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A COMPARATIVE ANALYSIS OF THREE PREDETERMINED MOTION-TIME SYSTEMS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

ABSTRACT

This study was concerned with the evaluation of results attained by three synthetic time study systems.

An industrial operation was filmed extensively, the film was viewed and a standard method was established for the cycle of operation. The cycle was divided into elements and times were obtained for the elements by film analysis and by each of the three synthetic time study systems under consideration.

The average film time was synthetically leveled so that the total difference between the film cycle and each standard data cycle was reduced to zero. The deviations between the elements of the average film cycle and the standard data cycles were determined for each of the standard data systems.

The elemental deviations were subjected to statistical analysis in an attempt to determine the difference in the abilities of the three standard data systems to measure the time for the given elements of work.

Within the limitations of the study, it was found that there was significant difference in the abilities of the three systems under consideration to measure the time for a given amount of manual work. It was also found that the times for the elements as determined by the Work Factor system best conformed to the times for the same elements as determined by film analysis, with BMT offering the next best measure and with MTM last.

CHAPTER I

INTRODUCTION

For many years management was an art based upon intuitive judgment and guess. There was little against which future production could be gaged except a backlog of experience. Taylor introduced to industry a different kind of methodology, which gave management a tool with which knowledge could be projected into the future. As stated by Person, "Taylor brought science to the aid of the art of management" (1).

Since antiquity, man has waged a slow but never ceasing battle to measure all of the elements which influence his life. The stimulus to attain these measures was furthered by the pure sciences and it was indeed late in the development of our culture that the need for like measures was felt by industry.

The advent of time study made it possible for management to put into quantitative units those values which had for so long remained as subjective judgment. With a method for accurately ascertaining the productive rate of people and machines, management could predict the outcome of its business endeavors with much greater accuracy than had been possible prior to the development of the technique of time study.

In the early development of time study Taylor recommended that work be divided into "its elementary units" for the purpose of time study (2). After time study had been conducted on the elementary units of work, the time for an entire cycle could be ascertained by simply adding the time values for the various parts of the cycle. The "elementary units" of work referred to by Taylor may be taken to mean units of work which the time analyst feels to be logical divisions of the work in question.

Gilbreth carried the division of elements of motion one step further when he classified all motion into seventeen basic elements, or therbligs (3). Holmes later made a step in the same direction by extending the number of therbligs (or basic elements) to twenty-four (4). The fundamental concept behind the formulation of therbligs was to classify all manual motion into constant, basic elements.

In conventional time study work, the main emphasis is upon elements of work which contain rather large groups of motions, rather than upon individual motions. The reasons for the method of division are two-fold. First, the time study analyst must select elements of work which are of sufficient length to be timed with a stopwatch, and second the analyst must be able to discern the end points of the elements. Since the stopwatch offers one of the most convenient methods of time study, the vast majority of all time study work is done in this manner. It also, however, offers one of the most inaccurate methods of timing.

There are two basic philosophies regarding the division of manual motions into elements. These two schools of thought were expressed by Gomberg as follows:

> Basically, standard data systems may be divided into two categories: the macroscopic and the microscopic. ----
> The macroscopic school generally formulates its data in terms of sizeable job elements that re-appear in many operations ---
> The microscopic school formulates its data in terms of minute muscular reactions, or therbligs (5).

The same general classification was noted by Abruzzi when he stated, "The principal difference between the two types of standard data is that the first (element standard data)* refers to motion groups and the second (motion standard data)* refers to individual motions" (6).

By means of independent research conducted on different groupings of elemental time data, Abruzzi was able to conclude that "an optimum grouping plan exists, beyond which a further reduction in the number of motion groups cannot expect to improve the degree of independence" (7). This was sufficient evidence for Abruzzi to generalize that element standard data was superior to motion standard data.

Segur, on the other hand, followed the basic pattern as outlined by Gilbreth and conducted extensive research in the field of motion and time study with therbligs as the basis of his study. Segur stated, "The most advantageous classification of motions which meets the requirements for motion study is the therblig------" (8).

A short explanation of the terms "standard data" is in order at this point. In this treatise, the above term is used to denote the standard-time values associated with a given sequence of manual motions. Several tables of such time values have been compiled and the term "standard data system" is used to denote the tables of values and the standard technique of application around which the tables were derived.

During the period around 1934-1935, extensive research conducted by A. B. Segur and Company led to the formulation of the first successful and economically potential system of applying standard time values to elements of a wide variety of industrial operations (9). Around the

*The insertions are the authors'.

same period, a group of men at R. C. A. were conducting research along the same line as that conducted by Segur. The results of the study of Quick, Shea and Koehler have been published as the Work-Factor System of synthetic time study (10).

Both of the above mentioned systems as well as several other more contemporary standard data systems are in current use in many industries. These various standard data systems are administered with sufficient accuracy to have definite utility in the industrial picture.

The concept of standardization is basic in all phases of pure science and engineering. Standardization of weights and measures, formulae and procedure, screw threads, and nomenclature are but a few examples. The practice can have equal applicability to industry, as in maintaining a classified record of discovered facts, of deriving from them standard objectives, methods and devices and collecting the recurrent activities into standard combinations of methods and devices. This is the basic procedure involved in the formulation and administration of element standard data, and to a greater extent in the case of motion standard data.

The use of any standard data systems presupposes uniformity of method and time of performance. Since there is a certain amount of normal variability inherent in all human movement, the probability of finding a motion performed in a certain manner is actually infinitesimally small. Even with considerable tolerance allowed to make the case practical there is still a considerable area outside the bounds of the standard motions. That is, the probability is still rather low that a given standard element will be discovered. As the number of adjacent motions is increased, the probability of observing exactly that sequence of motions is decreased. Therefore, as the size of the elements of element standard data is increased, the elements become more inflexible. This limitation was the main stimulus behind the formulation of standard data systems based on basic muscular reactions, or motion standard data systems.

The motion standard data systems are, however, not infallible. Since there is no absolute method of classifying human motion into basic components, several of these systems have come into existence. All of the contemporary systems differ one from the other in various respects. The matter of evaluating, or comparing these various motion standard data systems has posed several problems and has been a subject of heated debate.

In an exhaustive study of three motion standard data systems conducted by Davidson, sufficient evidence was submitted to prove the hypothesis:

> "If one of the several contemporary standard data systems is accurate, the others cannot be accurate" (11).

The results of the above cited studies cast serious doubt upon the theoretical correctness of the standard data technique in general. At best, it might be said that the systems are founded upon shaky ground.

The above cited studies, however, did not yield any results which could allow one to draw conclusions concerning the system which actually produced the best results in any given instance. Davidson stated that with the type of study that he conducted, "one could not say which one, if either, of the systems was actually valid" (12). The results of the studies, then, only allowed conclusions which were relative to the subjects of the particular study in question. Only limited generalizations could be drawn beyond the actual subjects.

The type of validation for the standard data system offered by the authors of the systems is based upon the fact that the applications of the system compare faverably with the results of independent time study (13). Therefore, a definite gap is left between the results of studies conducted on the fundamental concepts of the standard data theory and claims for validity which are based upon the correlation between application of the systems with independent time study. Any generalizations concerning the final outcome of any of the systems must bridge one important variable; the subjective judgment involved in the application of the systems. The subjective judgment of the application, while having one of the major influences upon the final outcome, is in itself, impossible to measure. What is needed, therefore, is a study designed to obtain reliable quantitative results which would not only allow conclusions to be drawn concerning the relative accuracy of various predetermined time standard systems, but also provides some insight into the absolute accuracy of the systems.

In order to conduct such a study as the one described above, two major obstacles must be overcome. First, the subjective judgment involved in the application of the systems must be minimized, and second, a scale must be devised against which the applications of the system may be measured.

The two obstacles, while being formidable, are by no means insurmountable. By considering the method in which the standard data systems were formulated and all of the published techniques employed in the successful application of the systems, it is logical to assume that as a person learns more and more about that particular system in which he is interested, he will increase his capability to accurately apply the system to actual operations. Stated in another manner, as a man gains in proficiency of application of the system he will also decrease any inaccuracy which might be due to misapplication. Therefore, the variation between the applications of two separate systems when both of the systems have been analyzed and applied to an operation by extremely competent persons, will be mainly due to the inaccuracies of the systems themselves.

Pertaining to the second obstacle, a scale against which the application of the system may be measured must necessarily be some form of time study of an actual operation. The most valid relationship between the results of application of a standard data system and an actual time study could be attained when exactly the same motions were covered by each and the most accurate time possible were attained for the motions.

Conclusions based upon such a study as briefly outlined above would necessarily have to be qualified in the light of the stated limitations. The results of such a study would, however, be more directly answerable to the claims of the proponents of the various standard data systems.

CHAPTER II

OBJECTIVE

The future of time study depends primarily upon the degree of accuracy attained in the measurement of the time required to perform manual operations. Standard data systems have proposed one method of measuring these times. As in the case of nearly all systems, some method of evaluating the results must be developed. This thesis is concerned with the development and application of a technique for evaluating the results attained by three standard data systems.

It was essential that the evaluation yield answers to the following questions:

(a) What are the relationships between the results attained by the standard data systems?

(b) Which of the standard data systems under consideration offers the best estimate of time for an actual operation?

These questions were answered by testing the hypothesis:

There is no significant difference in the ability of BMT, MTM or Work Factor to measure the time required to perform a short, manual operation.

It was suspected at the outset that sufficient evidence would be obtained to cause rejection of the hypothesis.

CHAPTER III

PROCEDURE

Acquisition of Data

Problem.--The problem involved in the thesis resolved itself to one of testing the results of application of three standard data systems. Davidson (14) and Abruzzi (15) took somewhat different approaches to the problems in that the results which they attained reflected upon the theoretical correctness of the systems. This study, on the other hand, was not concerned with the basic validity but with the results of application of the systems. Also included in this study was an analytical comparison between the elemental times of each standard data cycle and the measured elemental times for the manual cycle.

Source of Error.--Several considerations had to be given weight before such an evaluation could be undertaken. It was realized that the sources of variation of the final application of the systems might have come either from the inherent variability of the systems themselves or from the subjective judgment involved in the application of the system. Even though the sources of variation could not be quantitatively measured, an attempt was made to reduce the variation to a minimum by obtaining applications of the systems by persons who were very proficient in the field and who were qualified to teach the application of the systems and to use them in industrial situations.

General Procedure.--In order to give continuity to this treatise, a brief outline of the general procedure followed in the derivation and analysis of the data follows.

First, it was necessary to select a simple manual operation which would fulfill the following criteria:

(a) It would be available for study and analysis by the standard data experts.

(b) A sufficient quantity of accurate time data could be obtained for analysis.

Second, the standard data systems used in the analysis were selected. These systems were selected on a basis of availability of sufficient published material and the availability of expert advice concerning each of the systems.

Third, a cursory analysis of the film data of the operation was conducted in order to select a definite sequence of motions which would be considered as a standard cycle throughout the study. Also, all variations from the standard cycle were noted.

Fourth, an analysis of the standard cycle of the operation was conducted by an expert in the application of each of the selected standard data systems. The motions of the operation were divided into elements so as to include a minimum number of motions in each element.

Fifth, a large amount of accurate time data from film analysis of the operation was derived, using the elements as determined by the standard data systems. Mean element times and cycle times were computed.

Sixth, the film cycle means were adjusted to each of the standard data cycles, to compensate for the difference effected by the rating factor present in all of the standard data cycles.

Seventh, differences between the adjusted film element and the standard data element were computed.

Eighth, statistical analysis was conducted on these differences.

Derivation of Data

Selection and Preparation of Film Data.--In order to obtain a scale against which the results of the synthetic analysis might be measured, it was necessary to obtain extensive measurements of a manual operation. It was important that the selected operation be one for which the time values could be accurately ascertained and also one which would lend itself to easy synthetic measurement by standard data techniques. Toward this end, approximately 5000 feet of 16mm film were obtained, of the assembly of the Scripto T600 Ball Point Pen. The photography was done with a Kodak Cinespecial II Camera equipped with a 15mm, f-25 lens, driven by a synchronous motor at a constant speed of 2000 frames per minute.

The film used for this thesis was part of the film used for a project sponsored by the Georgia Institute of Technology Research Committee and under the direction of Doctors R. N. Lehrer and J. J. Moder.

The subject of the study was selected as a result of previous work conducted by Lind (16) and Taft (17). In their studies, the work time distribution of nineteen operators performing the same operation as were used as the vehicle of this study, were statistically analyzed. The two operators whose work time distributions were the most stable were selected as subjects of this study.

The first operator (to be called operator A throughout the remainder of this thesis) was filmed continuously, with the exception of film change times, from 10:38 A.M. until 11:37 A.M. of April 14, 1954. During the elapsed time, ten 200 foot rolls of film were taken.

The second operator (to be called operator B throughout the remainder of this thesis) was filmed continuously except for film change time, between 12:28 P.M. and 1:44 P.M. of the same day, fifteen, 200 foot rolls of 16 mm film being taken during that time.

Both of the operators were quite proficient at the job as the stability of their work time distributions would indicate, both having had considerably more experience than that considered by the company as minimum necessary to become proficient. Operator A had acquired 19 months experience at the time the films were taken, and operator B had worked at the job for 23 months. Both operators were considered excellent workers.

Initial Film Review.--In order that the results of the synthesized time for the operation and the value derived from the films be directly comparable, it was necessary that exactly the same amount of work be included in each analysis. Therefore, a definite sequence of motions was defined as being the standard cycle so that some base could be established against which variations might be gaged.

Some question might be raised concerning the elimination of certain variations from our normal work cycle, since a certain number of these variations are inherent in manual work. For the purpose of this thesis, however, it was only necessary that consistency be attained. That is, it was necessary that exactly the same amount of work be included in each cycle of operation which was to be used as a measure of the true time for the operation.

A Keystone 16 millimeter projector equipped with a frame counter and a special control box which allowed the film to be run in either direction or stopped on any frame was used for the initial analysis of the film. A cursory analysis of the film was first made and a definite sequence of motions was defined as being a standard cycle. The standard cycle in shown in Table 1.

After a standard cycle had been defined, a second and much more exhaustive analysis was made of all of the film. During this analysis, the length of the element of motion was not determined, however, all variation from the normal cycle of operation was ascertained. There were sixty such notable variations, which might be considered as assignable causes of variation. These sixty variations from the normal cycle are tabulated in Table 20 in the appendix.

It was necessary for the purpose of this study that equal amounts of work be included in all cycles which were to be used as a true measure of the operation time and in each of the synthesized cycles. It was therefore decided that the cycles must meet the following criteria: 1.-They must be free from all assignable causes of variation. 2.-They must be preceded by a cycle which did not contain an assignable cause of variation in the last half of the cycle. Therefore, in addition to noting the type of deviation from the normal cycle which occurred, it was also noted which half of the cycle contained the variable. One half of the cycle was defined as being that portion from the first movement of the hand to pick up the completed unit after the insertion of the ferrule, to the first motion away from the dispose tray after the completed units have been disposed.

By way of definition, the term "assignable cause of variation" is being used to denote those deviations from the established standard pattern of motion which could be discerned by detailed film analysis.

A total of 461 cycles of the operation were analyzed. The number of cycles contained by each roll of film and the type and position of

Table 1. Standard Work Cycle

Ele. No.	Element	Left Hand	Right Hand
1	Get bbl.	Reach 18 in. to bbl. tray, grasp bbl.	Move 18 in. Dispose two completed units. Reach 7 in. to bbl. tray and grasp bbl.
2	Place bbl.	Move bbl. 9 in. Turn clip toward operator. Insert pen 1 in. into jig with hand. Insert 4 in. into jig with index finger.	Move bbl. 9 in. Turn clip toward operator. Reach index finger to top of bbl. Insert bbl. 1 in. into jig with hand, 4 in. with index finger.
3	Get unit	Reach 10 in. to left side, grasp writing unit.	Reach 10 in. to left side. Grasp writing unit.
4	Place unit	Move unit 10 in. to bbl. Align, insert 2 in., release, re-grasp and insert 2 in. with index finger.	Move unit 10 in. to bbl. Align, insert 2 in., release, re-grasp and insert 2 in. with index finger.
5	Get drive nut	Reach 3 in. to drive nut tray, select and grasp one.	Reach 3 in. to drive nut tray, select and grasp one.
6	Place drive nut	Move drive nut 3 in. to jig (Pre-position in route 70% of time). Align with bbl., engage threads, release, re-grasp and screw drive nut onto bbl.	Move drive nut 3 in. to jig (Pre-position in route 70% of time). Align, engage threads, release, re-grasp and screw drive nut onto bbl.
7	Get ferrule	Reach 6 in. to ferrule tray, select and grasp one ferrule.	Reach 6 in. to ferrule tray, select and grasp one ferrule.

Table 1. Standard Work Cycle (Continued)

Ele. No.	Element	Left Hand	Right Hand
8	Place ferrule	Move ferrule 7 in. to jig. (Pre-position in route 30% of time). Align and insert ferrule onto bbl.	Move ferrule 7 in. to jig. (Pre-position in route 30% of time). Align and insert ferrule onto bbl.
9	Get and place comp. unit	Slide hand 1 in. down bbl. Grasp bbl., lift 4 in. up. Move 5 in. down and toward operator's body while rotating point 90° toward body. Move bbl. 1 in. to jig, insert 1 in. into stake hole.	Slide hand 1 in. down bbl. Grasp bbl., lift 4 in. up. Move 5 in. down and toward operator's body while rotating point 90° toward body. Move bbl. 1 in. to jig, insert 1 in. into stake hole.
10	Stake	Move body forward slightly, applying 2 lbs. pressure on pens while simultaneously pressing foot pedal. Move body back.	Move body forward slightly, applying 2 lbs. pressure on pens while simultaneously pressing foot pedal. Move body back.
11	Remove comp. unit, give left to right	Withdraw comp. unit 6 in. Move toward right hand. Release pen.	Withdraw comp. unit 12 in. Move toward left hand. Release slightly, then grasp left unit.

each variable as shown in Table 21 in the appendix. The cycles which were found to meet the above criteria are shown in Table 2.

Derivation of Standard Data.--In making a selection of standard data systems to be included in the study, it was necessary that they fulfill two requirements. First, in order that an adequate presentation of the background philosophy underlining each system be made, sufficient published material concerning the system had to be available. This was a rather serious requirement since some of the standard data systems have retained secrecy concerning the derivation of the time values and the method of application necessary for acceptable results.

Second, it was essential that expert advice be available concerning the application of each of the systems.

The systems which were found to meet the above qualifications were BMT (Basic Motion Time Study), MTM (Method Time Measurement), and Work Factor.

In order that the evaluation of the application of the systems be truly representative of the greatest precision of measurement of which the systems were capable, it was necessary that an extremely qualified person in each field be employed to perform the analyses. Therefore, an expert in each field was contacted and supplied with the necessary amount of information and equipment for the performance of the analysis.

Each expert analyst was furnished with one 200 foot roll of 16mm film of the operation and a Keystone analysis projector. Also, a complete tabulation of all sizes and weights of articles handled, all distances moved by each hand in the performance of the standard work cycle frequencies of all included variables were furnished.

Table 2. Cycles Analyzed for Study of Consistency and Accuracy of Synthetic Time Study Data

Film No.	Cycle No.	Count
X1	13, 18, 19, 20, 23	5
X4	10, 11, 12, 16, 17, 20, 21, 22, 23, 24, 25	11
X5	4, 7, 8, 9, 10, 12, 14, 15, 17	9
X6	13, 14, 15, 22, 23	5
X7	1, 18	2
X8	5, 6, 7	3
X9	1, 2, 15, 19	4
X10	12	1
		40

Samples of all parts of the pen were also given to the analysts.

An effort was made to offer exactly the same conditions to each analyst so that the results might be directly comparable and it is believed that these conditions were held constant. The results of the analyses of the experts are given in Tables 3, 4, and 5.

The standard data systems do not all include exactly the same amount of work in each element. This is exemplified by two of the systems under consideration. Whereas MTM separates the times for "Reach" and "Grasp" into two classes of motions with defined categories in each, BMT has these two classes of motion combined into one, with a definite number of categories of this class. In order to be certain that the elemental times of the various systems were being combined into larger elements which contained exactly equal amounts of work, it was reasoned that the method of elemental grouping used by the systems which itself contained the larger unit times should be allowed to determine the method of division to be used by the other standard data systems and in the film analysis. Among the systems being considered in the experiments, BMT best met this requirement. Therefore, the method of grouping the motion times employed in the BMT analysis was also used in the other analyses.

<u>Final Film Analysis</u>.--The selected cycles of the film were then analyzed and the exact number of frames included in each element was determined. Since the film was taken at a constant speed of 2000 frames per minute, it was a simple matter to convert the data from units of frames to minutes by dividing by 2000. The result of this analysis is tabulated in Table 22 in the appendix.

Table 3. BMT Analysis

No.	Left Hand Element	Symbol	Time	Time	Symbol	Right Hand Element
1	Get bbl.					Dispose comp. units.
	Reach toward bbls.	R18C	98	98	M18C	Reach disp. tray.
	Separate bbls.	M1/2B	32	74	R7C	Reach toward bbls.
	Grasp one bbl.	R1/2C	41	32	M1/2B	Separate bbls.
				41	R1/2C	Grasp bbl.
			171	245		
2	Place bbl.					Place bbl.
	Move bbl. to jig.	M9CV	87	87	M9CV	Move bbl. to jig.
		P1/8	60	60	P1/8	
		Simo6	30	30	Simo6	
				48	R1C	Reach finger to top bbl.
	Push bbl. to bottom jig.	M4B	49	49	M4B	Push bbl. to bottom jig.
			226	274		
3	Get unit.					Get unit.
	Reach to tray.	R10C	81	81	R10C	Reach to tray.
	Separate units.	M1/2B	32	32	M1/2B	Separate units.
	Grasp unit.	R1/2C	41	41	R1/2C	Grasp units.
		P1/8	62	62	P1/8	
		Simo24	82	82	Simo24	
			298	298		
4	Place unit.					Place unit.
	Move unit to bbl.	M10CV	90	90	M10CV	Move unit to jig.
		P1/8	62	62	P1/8	
		Simo6	30	30	Simo6	
	Insert unit.	M2B	42	42	M2B	Insert unit.
	Re-grasp unit.	R2C	55	55	R2C	Re-grasp unit.
	Seat unit.	M2B	42	42	M2B	Seat unit.
			321	321		
5	Get drive nut.					Get drive nut.
	Reach to tray.	R3C	60	60	R3C	Reach to tray.
	Separate nuts.	M1/2B	32	32	M1/2B	Separate nuts.
	Grasp nuts.	R1/2C	41	41	R1/2C	Grasp nut.
		P1/4	18	18	P1/4	
		Simo4	18	18	Simo4	
			169			

Table 3. BMT Analysis (Continued)

No.	Left Hand Element	Symbol	Time	Time	Symbol	Right Hand Element
6	Place and assemble drive nut. No pre-position 30%.					Place and assemble drive nut.
	Move to bbls.	M3CV	67	67	M3CV	Move to bbl.
		P1/32	102	102	P1/32	
		Simo6	47	47	Simo6	
	Engage threads.	M1/2B	32	32	M1/2B	Engage threads.
	Re-grasp drive nut.	R2C	55	55	R2C	Re-grasp drive nut.
	Tighten drive nut.	M1B	36	36	M1B	Tighten drive nut.
			339	339		
	339 x .30 =		101.7			
6A	Place and assemble drive nut. Pre-position 70%.					
		M3CV	67	48	M2BV	Move to assembly.
				41	R1/2C	Re-grasp.
				32	M1/2B	Turn drive nut.
				41	R1/2C	Re-grasp.
				48	M1C	Turn drive nut.
		P1/32	90	90	P1/32	On M1C.
		Simo6	47	47	Simo6	
	Engage threads.	M1/2B	32	32	M1/2B	Engage threads.
	Re-grasp drive nut.	R2C	55	55	R2C	Re-grasp drive nut.
	Tighten drive nut.	M1B	36	36	M1B	Tighten drive nut.
			327	470		
	470 x .70 =			329		
7	Get ferrules.					Get ferrules.
	Reach tray.	R6C	71	71	R6C	Reach tray.
	Separate ferrules.	M1/2B	32	32	M1/2B	Separate ferrules.
	Grasp ferrule.	R1/2C	41	41	R1/2C	Grasp ferrule.
		P1/4	25	25	P1/4	
		Simo6	27	27	Simo6	
			196	196		
8	Place ferrule. No pre-position 70%.					Place ferrule. No pre-position 70%.
	Move to bbl.	M7CV	74	74	M7CV	Move to bbl.
		P1/32	117	117	P1/32	
		Simo6	47	47	Simo6	

Table 3. BMT Analysis (Continued)

	Left Hand			Right Hand		
No.	Element	Symbol	Time	Time	Symbol	Element
8	Slide ferrule on bbl.	M1/2B	32	32	M1/2B	Slide ferrule on bbl.
			270	270		
	270 x .70 =		189			
8A	Place ferrule, pre-position 30%.					
		M7CV	82	63	M6BV	Move toward jig.
				41	R1/2C	Re-grasp.
				32	M1/2B	Turn ferrule.
				41	R1/2C	Re-grasp.
				48	M1C	Turn ferrule.
	On M1C	P1/32	90	90	P1/32	On M1C.
		Simo6	47	47	Simo6	
	Slide ferrule onto bbl.	M1/2B	32	32	M1/2B	Slide ferrule onto bbl.
			251	394		
	394 x .30 =			118.2		
9	Grasp comp. unit and remove from jig					Grasp comp. unit and remove from jig.
	Grasp bbl.	R1C	48	48	R1C	Grasp bbl.
	Lift unit from jig.	M4B	49	49	M4B	Lift from jig.
	Bring down to stake.	M5B	52	52	M5B	Bring down.
	Push into jig.	M1C	41	41	M1C	Push into jig.
	On M1C	P1/32	90	90	P1/32	On M1C.
		Simo6	47	47	Simo	
	Seat in jig.	M1A	30	30	M1A	
	(2)	F2#	4	4	F2# (2)	
			361	361		
10	Stake					
				55	FM	Depress pedal.
				55	FM	Depress pedal.
				110		

Table 3. BMT Analysis (Continued)

	Left Hand			Right Hand		
No.	Element	Symbol	Time	Time	Symbol	Element
11	Remove units.					
	Give left to right.	M6C	71	86	M12C	
	Grasp.	R2C	55			
			126	86		
	Total Cycle	2837.9				

Table 4. MTM Analysis

	Left Hand				Right Hand
No.	Element	Symbol	Time	Symbol	Element
1	Reach to bbls.	R18C	17.0	M18B	To box with 2 pens.
			2.0	RL1	Release pens in box.
			8.0	R7C	Reach to bbls.
	Grasp one bbl.	G4B	9.1		
			9.1	G4B	Grasp one bbl.
			45.2		
2	Bbl to fixture.	M9B	11.5	M9B	Bbl. to fixture.
	Turn to position clip.	T90S		T90S	Turn to position clip.
		G2		G2	
	Bbl. into fixture.	M1C	2.0	M1C	Bbl. into fixture.
		P1SE	5.6	P1SE	
			2.0	R1A	Index finger to top bbl.
	Index finger to top bbl.	M3A	4.9	M3A	Push bbl. home.
		RL1		RL1	
		RL2	0.0	RL2	Index finger.
			26.0		
3	To writing units.	R10C	12.9	R10C	To writing units.
			10.8	G1C3	Grasp one unit.
	Grasp one unit	G1C3	10.8		
			34.5		
4	Unit to bbl.	M10B	13.5	M10C	Unit to bbl.
			11.2	P1SD	Unit into bbl.
	Unit into bbl.	P1SD	11.2		
		M1C	2.0		
	Release unit.	RL1	2.0	RL1	Release unit.
			39.9		
5	To drive nut	R3C	7.3	R3C	To drive nut.
			9.1	G4B	Grasp one nut.
	Grasp one nut	G4B	9.1		
			25.5		

Table 4. MTM Analysis (Continued)

	Left Hand			Right Hand	
No.	Element	Symbol	Time	Symbol	Element
6	Drive nut to assembly.	M3C	5.7	M3B	Drive nut to assembly.
	Pre-position in transit.	G2		G2	Pre-position in transit.
		P1SSE	11.2		Drive nut to assembly.
			2.0	M1C	
	Drive nut to assembly.		11.2	P1SSE	
	Engage threads.	M1B		M1B	
	Release.	RL2	0.0	RL2	
	Reach.	R2A	4.0	R2A	
	Grasp.	G5	0.0	G5	
	Turn drive nut.	M1B	2.9	M1B	
	Release.	RL1	2.0	RL1	
			39.0		
7	To ferrule.	R6C	10.1	R6C	To ferrule.
	Grasp one ferrule.	G4C	12.9		
			12.9	G4C	Grasp one ferrule.
			35.9		
8	Move to assembly.	M6C	9.7	M6C	Move to assembly.
	Pre-position in transit.	G2		G2	Pre-position in transit.
	Position	P1SE	5.6	P1SE	Position.
	Release ferrule.	RL1	2.0	RL1	Release ferrule.
			17.3		
9	Reach comp. unit.	R1A	2.0	R1A	
	Grasp bbl.	G1A	2.0	G1A	
	Lift out of fixture.	M4B	6.9	M4B	
	To horizontal.	M5B	8.0	M5B	
	Pre-position.	G2		G2	
	Push into hole.	M1C	2.0	MTC	
	Position	P1SE	5.6	P1SE	
	To seat ferrule.	AP2	10.6	AP2	
			37.1		

Table 4. MTM Analysis (Continued)

	Left Hand			Right Hand	
No.	Element	Symbol	Time	Symbol	Element
10	Stake		8.5	FM	
			8.5	FM	
			17.0		
11	Remove from jig.	D1E	4.0	D1E	
	To RH.	M6A	12.9	M12A	
		G3	5.6	G3	
			22.5		
	Total		339.9		

Table 5. Work Factor Analysis

	Left Hand				Right Hand	
No.	Element	Symbol	Time	Time	Symbol	Element
1	Get bbls.					
	Reach bbls.	A18CD	98	76	A18D	Reach dispose tray. (Release bbls. simo with change direction.)
				65	A7CD	Reach bbls.
	Separate bbls.	F1	16	16	F1	Separate bbls.
	Grasp bbls.	F1C	23	23	F1C	Grasp bbls.
				180		
2	Place bbls. in jig.					
	Move bbl. to jig.	A9D	58	58	A9D	Move bbls. to jigs.
	Align point with hole.	A1CD	34	34	A1CD	Align point with hole.
	Simo (25% of 34)	Simo	8.5	8.5	Simo	Simo (25% of 34)
	Done simo with grasp. Or in transit - No time	F1		16	F1	Approach bbl. tip/finger
	Insert bbls. with finger.	F2	17	17	F2	Insert bbl. with finger.
	Release bbl.	1/2F1	8	8	1/2F1	Release bbl.
				141.5		
3	Get unit.					
	Reach tray.	A10CD	78	78	A10CD	Reach tray.
	Contact units.	F1	16	16	F1	Contact units.
	Simo (25% of 16)	Simo	4	4	Simo	Simo (25% of 16)
	Grasp units.	F1C	23	23	F1C	Grasp units.
	Simo (25% of 23)	Simo	5.75	5.75	Simo	Simo (25% of 23)
			126.75			
4	Place unit.					
	Lift to clear tray.	A2	20	20	A2	Lift to clear tray.
	Move unit to bbl.	A10CD	78	78	A10CD	Move unit to bbl.
	Align point with hole.	A1CD	34	34	A1CD	Align point with hole.

Table 5. Work Factor Analysis (Continued)

No.	Left Hand Element	Symbol	Time	Time	Symbol	Right Hand Element
4	Simo (25% of 34)	Simo	8.5	8.5	Simo	Simo (25% of 34)
	Insert unit.	A2D	29	29	A2D	Insert unit.
	Approach unit tip.	A2	20	20	A2	Approach unit tip.
	Contact unit tip and force into bbl.	A2D	29	29	A2D	Contact unit tip and force into bbl.
			218.5			
	Release simo with ending of above.					Release simo with ending of above.
5	Get drive nut.					
	Reach tray	A3D	32	32	A3D	Reach tray.
	Contact nuts.	F1	16	16	F1	Contact nuts.
	Simo (25% of 16)	Simo	4	4	Simo	Simo (25% of 16)
	Grasp 1 nut.	F1	16	16	F1	Grasp 1 nut.
	Simo (25% of 16)	Simo	4	4	Simo	Simo (25% of 16)
			72			
6	Place and assemble drive nut					
	Move nut to bbl. (Pre-position done in transit.)	A3CC	41	41	A3CC	Move nut to bbl. (Pre-position done in transit.)
	Align with bbl.	A1CD	34	34	A1CD	Align with bbl.
	Simo (25% of 34)	Simo	8.5	8.5	Simo	Simo (25% of 34)
	Seat on bbl. (no resistance 90%.)	A1CD	30.6	30.6	A1CD	No resistance 90%.
	With resistance 10%.	A1RD	3.4	3.4	A1RD	With resistance 10%.
	Engage threads.	F2	17	17	F2	Engage threads.
	Simo (25% of 17)	Simo	4.25	4.25	Simo	Simo (25% of 17)
	Reach to re-grasp.	F2	17	17	F2	Reach to re-grasp.
	Simo (25% of 17)	Simo	4.25	4.25	Simo	Simo (25% of 17)
	Grasp.	F1C	23	23	F1C	Grasp
	Simo (25% of 23)	Simo	5.75	5.75	Simo	Simo (25% of 23)
	Fix threads.	F1	16	16	F1	Fix threads.
	Simo (25% of 16)	Simo	4	4	Simo	Simo (25% of 16)
	Release	1/2F1	8	8	1/2F1	Release
			216.75			
7	Get ferrules.					
	Reach tray	A6D	47	47	A6D	Reach tray.

Table 5. Work Factor Analysis (Continued)

	Left Hand					Right Hand
No.	Element	Symbol	Time	Time	Symbol	Element
7	Contact ferrules.	F1	16	16	F1	Contact ferrules.
	Simo (25% of 16)	Simo	4	4	Simo	Simo (25% of 16)
	Grasp ferrules	F1	16	16	F1	Grasp ferrules.
	Simo (25% of 16)	Simo	4	4	Simo	Simo (25% of 16)
			87			
8	Place ferrules.					
	Move to bbl. (Pre-position done in transit.)	A7C	51	51	A7C	Move to bbl. (Pre-position done in transit.)
	Align with bbl.	A1CD	34	34	A1CD	Align with bbl.
	Simo (25% of 34)	Simo	8.5	8.5	Simo	Simo (25% of 34)
	Fit over bbl.	F1R	23	23	F1R	Fit over bbl.
			116.5			
9	Move comp. assembly to stake jig.					
	Slide fingers down bbl to P.U.	F1	16	16	F1	Slide fingers down bbl. to P.U.
	Lift assembly from jig.	A4D	38	38	A4D	Lift ass'y. from jig.
	Bring assemby down to stake, pre-position in transit.	A5CD	55	55	A5CD	Bring assembly down to stake, pre-position in transit.
	Move to jig.	A1CC	34	34	A1CC	Move to jig.
	Simo (25% of 34)	Simo	8.5	8.5	Simo	Simo (25% of 34)
	Seat in jig.	A1	18	18	A1	Seat in jig.
			169.5			
10	Stake.	FT3	24	24	FT3	
	Press pedal.	FT3	24	24	FT3	
			48			
11	Remove assembly - give left to right.					
	Remove - out.	A6D	47	47	A12D	Remove - out.
	Hold.	1/2F1	8	8	1/2F1	Grasp unit.
	Release.	1/2F1	8	8	1/2F1	Hold.
			63			

Total 1439.50 or .14395 mins.

CHAPTER IV

TREATMENT OF DATA

Analysis of Film Data

Frequency Distributions.--Frequency distributions for each element and for the total of all elements were plotted and appear as histograms in Figures 1 through 12 in the appendix.

Two methods were considered for the calculation of the total cycle time. The first alternative was to complete the "true" cycle time by taking the difference between the first frame and the last frame of the cycle. Since both hands began and ended all cycles simultaneously, the total cycle time of each hand would thus be obtained. The cycle time is computed in this manner and distributed in Figure 12 in the appendix.

The standard data systems, on the other hand, determine their total cycle time by utilizing "the principle of the limiting motion" (18). This principle states roughly that when two motions are performed at the same time, it is the motion which requires the longer time that determines the overall time required. Over and above this, in many cases, is applied an additional factor to compensate for the slowdown inherent in simultaneous motions. In order that the resulting film times be directly comparable with the synthesized times, the same methodology was used in the computation of the film cycle times were computed by adding the time values for the hands which required the greater time, element by element. This had an effect of increasing the total cycle times. The mean total cycle time, however, was only increased by .00035 minutes or .25% of the cycle time by the above procedure. See Figure 13 in the appendix for the distribution of these times.

It was at once evident from a review of the two frequency distributions and from the small change in the mean cycle time that the two methods offered results which were well within the limits of accuracy of the study.

Analysis of Extreme Values.--Examination of the distribution of time values for the elements of the cycles indicated that some of the values might be outside of the "normal" range. It was decided that these extreme values should be re-analyzed to determine if any "assignable" cause for the variation could be determined. It was felt that the use of such a criterion of selection as three sigma limits would not necessarily be valid since there was a gross lack of normality in some elemental distributions. It was therefore decided that all values which seemed even slightly distant should be re-analyzed.

There is no definite line of demarcation between an assignable cause of variation and a nonassignable cause of variation. The criterion used in the selection of the first set of variations was that the variables be large enough to be detected by detailed film analysis. Upon re-analysis of the extreme element times, six elements were found to contain "assignable" causes of variation which were not discovered in the first analysis. These variations were slight but accountable in light of the original criteria.

It was decided to test the effect of the six variable elements upon the whole set by conducting a two factor analysis of variance on the film data, comparing the variance of the columns, or cycles, to the residual. It was decided that an F ratio of greater than 5% significance would be sufficient cause of eliminating the elements from the data.

The main types of variability were caused by:

1. Differences between rows: 11 elements with 10 degrees of freedom.
2. Differences between columns: 40 cycles with 39 degrees of freedom.
3. Residual, due to experimental error plus interaction between row and column factors with 390 degrees of freedom.

If further information is desired concerning the analysis of variance, it may be attained by consulting a number of statistical text.

The results of the analysis are shown in Table 6.

Comparison between the column variance and the residual variance yielded the following results:

$$F = \frac{7.34 \times 10^{-6}}{7.67 \times 10^{-6}} = .957$$

By consulting the proper table, it was found that at the 5% level of significance and 39 and 390 degrees of freedom, the F ratio was 1.51. The fact that the calculated values for F was less than the value found in table indicated that the results were less significant than the 5% level of the table. Accordingly, the questionable elements were allowed to remain in the data.

The average of the film times for each element was computed to be used as the base against which the synthesized times could be compared.

Table 6. Two Factor Analysis of Variance

	Sum of Squares	Degrees of Freedom	Mean Square
Between Rows	.013575	10	.00135746
Between Columns	.000286	39	.00000734
Residual	.002990	390	.00000767
Total	.016851	399	.00004223

These times as well as a summary of the times derived by the various synthetic systems are shown in Table 7.

Studies of Variance.--The variance of the distribution of the time values of each of the elements was computed. These values are tabulated in Table 8.

The distribution of the variances and the distributions of the time values for the various elements suggested a possible division of the elements into two groups of "Get" and "Place" elements which might have correlation with the variances. In the division of the elements, a "Get" element was restricted to those getting an object from a source other than the opposite hand, and "Place" elements were restricted to those placing an object other than in the opposite hand. Computation of the variances for categories of "Get" and "Place" elements tended to prove the assumption. These calculations are indicated in Tables 9 and 10.

It should be noted that elements 10 and 11 were omitted from the classification in Tables 9 and 10. These elements did not fit into either of the designated categories.

It was at once obvious that the mean variance of the "Place" element was much greater than that of the "Get" elements. The differences between the variances of the two classes of elements might be ultimately explained by one of the following:

(a) The inherent complexity of the element.

(b) The terminal precision involved in the place elements.

(c) The eye-hand coordination required.

Insufficient data were available in this study to rigorously test any of the above propositions. The categories of elements did,

Table 7. **Summary of all Synthesized and Film Times Expressed in Minutes**

Ele. No.		Film Values	BMT	MTM	Work Factor
1	Get barrel	.01355	.02450	.02712	.018000
2	Place barrel	.01151	.02740	.01560	.014150
3	Get unit	.00799	.02980	.02070	.012675
4	Place unit	.02041	.03210	.02394	.021850
5	Get drive nut	.00840	.01690	.01530	.007200
6	Place drive nut	.02139	.04307	.02340	.021675
7	Get ferrule	.00786	.01960	.02154	.008700
8	Place ferrule	.01135	.03072	.01038	.011650
9	Get and place comp. unit	.02119	.03610	.02226	.016950
10	Stake	.00941	.01100	.01020	.004800
11	Give left to right	.00538	.01260	.01350	.006300
	Total	.13844	.28379	.20394	.143950

Table 8. **Elemental Variances**

Ele. No.	Description	$\sigma^2 \times 10^{-6}$
1	Dispose P. U. bbls.	2.25
2	Place bbls.	3.18
3	Get units.	6.86
4	Place units.	18.82
5	Get drive nuts.	6.80
6	Place drive nuts.	11.18
7	Get ferrules.	5.07
8	Place ferrules.	17.29
9	Get and place comp. units.	9.96
10	Stake	1.21
11	Remove, give left to right.	1.37

Table 9. Get Elements

Ele. No.	Description	$\sigma^2 \times 10^{-6}$
1	Dispose and pick up bbls.*	2.25
3	Get units.	6.86
5	Get drive nuts.	6.80
7	Get ferrules	5.07
	Total	20.98

Mean Variance $= \sigma^2 \quad \frac{20.98}{4} = 5.25$

Table 10. Place Elements

Ele. No.	Description	$\sigma^2 \times 10^{-6}$
2	Place bbls.	3.18
4	Place units.	18.82
6	Place drive nuts.	11.18
	Place ferrules.	17.29
9	Get and place comp. units.**	9.96
	Total	60.43

Mean Variance $= \sigma^2 = \frac{60.43}{5} = 12.09$

*The Get part of this element was considered dominant.

**The Place part of this element was considered dominant.

however, indicate the possibility of some systematic variance.

In order to test the homogeneity of the variance of the eleven elements, Bartlett's Test was employed. This test indicates the probability that a given set of variances were extracted from the same homogeneous population. It was strongly suspected at the outset that this test would yield results indicative of the fact that the variances were not homogeneous. The reasoning behind the suspicion was based upon the fact that the different types of elements required varying amounts of dexterity and eye-hand coordination, as indicated in the previous comparison between "Get" and "Place" elements.

The variances of the elements had been previously computed. In order to conduct Bartlett's Test, it was necessary to compute the natural logarithm of the element variances.*

The assumption of lack of homogeneity of variance was substantiated by the results of the test which indicated a ratio of B/C of 151.916. The value from the χ^2 table at the 5% level of significance and 10 degrees of freedom was 18.21. The relationship between the calculated ratio of B/C and the value from the χ^2 table made it evident that the probability of the variances being homogeneous was much less than .05. Stated in another manner, if the variances were from the same population, a happening with much less than .05 probability had occurred.

Since the results of Bartlett's Test indicated a lack of homogeneity of variances and since the previous grouping of the variances

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*A detailed description of Bartlett's Test may be found in many statistical text books.

into "Get" and "Place" elements gave strong indication of a systematic variance, it was suspected that a correlation might exist between the variances and some other variable. In an attempt to discover such a relationship, the mean and the variances of the elements were tabulated in Table 11. Inspection of Table 11 indicated the possibility of a linear correlation between those two statistics. In order to ascertain whether or not such a relationship did exist, a correlation coefficient was computed.

The computed value of the correlation coefficient was found to be .571 while the value from the table of correlation coefficient for 9 degrees of freedom at the 5% level of significance was .521. Since the computed value of the correlation coefficient was larger than the value found in the appropriate table for the given conditions, it was concluded that either a linear correlation did exist or a chance happening had occurred which had a probability of less than 1/20.

An estimate of the per cent of variance due to the relationship with the mean was $r^2 \times 100$ or 32.6%.

Analytical Comparison Between Systems and Film Cycle

Normalization of Film Data.--The data obtained from the films were, of course, taken at the speed at which the operator was performing, whereas the data from the standard data analyses, had been "normalized". This means that the values from the standard data tables reflected the time that should be required for a given operation by an "average" operator performing at "normal" pace. Therefore, the film data and the synthesized data were separated by a certain unknown factor; a rating factor which had been applied to the standard data in the derivation of the standard

Table 11. Elemental Mean and Variance

Element Number	Mean $\bar{X} \times 10^{-2}$	Variance $\sigma^2 \times 10^{-6}$
1	1.4	2.25
2	1.2	3.18
3	.8	6.86
4	2.0	18.82
5	.8	6.80
6	2.1	11.18
7	.8	5.07
8	1.1	17.29
9	2.1	9.96
10	.9	1.21
11	.5	1.37
Total	13.7	

values.

In order to directly compare each synthesized time to the normal, or film time, it was therefore necessary to eliminate the difference effected by the rating or leveling factor. This was accomplished by determining the ratios of the total of each of the film times respectively and the total mean film time, thus:*

1. $$\frac{\text{BMT (Total Cycle)}}{F_t \text{ (Mean Cycle)}} = K_1$$

2. $$\frac{\text{MTM (Total Cycle)}}{F_t \text{ (Mean Cycle)}} = K_2$$

3. $$\frac{\text{Work Factor (Total Cycle)}}{F_t \text{ (Mean Cycle)}} = K_3$$

The above procedure eliminated from this study the effect of the difference caused by rating, or pace, and placed full concentration upon the variation of the elements of the synthesized cycles from the mean film elements. Therefore, all inferences made from this study were necessarily drawn only from the variations between the elements of the synthesized cycle and elements of the film cycle.

Serious consideration was given to the procedure of synthetically leveling the film data in the manner described above. The procedure increases the inherent variance of the film data. However, due to the fact that the standard data tables were derived by a similar procedure, it was reasoned that the film data would have to be leveled in order

*In order to use this procedure, it was necessary to assume that the total difference between the mean of the film values and the mean of the standard data cycle was due entirely to the presence of the leveling factor in the standard data.

that valid results might be achieved. The adjusted film values appear in Tables 13, 14, and 15.

After the film values were adjusted to each of the standard data cycles, the differences between the elements of the adjusted film cycle and the standard data cycle, respectively, were computed both as relative values and as percentages of the film values as shown in Table 12.

It should be noted that the total difference between all elements (that is, the total relative error) was forced to equal zero by the method of normalization employed. Since only the internal consistency between the elements of the adjusted film cycle and the synthesized cycle was being tested, this in no way affected the results.

In addition to the relative elemental errors (shown as C_{B_i} in Table 12) and the percentage elemental errors (shown as P_i in Table 12) the following values were computed for comparison purposes, all of these values are tabulated in Table 16.

(a) The average absolute error was computed by simply dividing the total absolute value of the errors by the number of elements, 11.

(b) The average relative per cent error was computed by dividing the total relative per cent error by the number of elements.

(c) The average absolute per cent error was calculated by dividing the total absolute per cent error by the number elements.

(d) The standard deviation of the relative errors was computed.

(e) The standard deviation of the per cent errors was calculated.

Some of the calculations described above were somewhat redundant but were presented in order that the reader might get a clear picture of the internal, or elemental consistency of the three systems with respect

Table 12. Method of Normalization of Film Data

Element Number	Adjusted Film Cycle	BMT Cycle	$C_{Bi} = (F_i - B_i)$	$P_i = C_{Bi}/F_i$
1	F_1	B_1	C_1	P_1
2	F_2	B_2	C_2	P_2
3	F_3	B_3	C_3	P_3
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
11	F_{11}	B_{11}	C_{11}	P_{11}

Table 13. Comparison Between Adjusted Film Times and BMT Times

Ele. No.	Adjusted Film Times	BMT Times	C_{Bi} = Fi-Bi	%C = $\frac{Fi-Bi}{Fi}$ x 100
1	.02778	.02450	+.00328	+11.807
2	.02359	.02740	-.00381	-16.151
3	.01638	.02980	-.01342	-81.929
4	.04184	.03210	+.00974	+23.279
5	.01722	.01690	+.00032	+ 1.858
6	.04385	.04307	+.00078	+ 1.779
7	.01611	.01960	-.00349	-21.664
8	.02327	.03072	-.00745	-32.015
9	.04344	.03610	+.00734	+16.897
10	.01929	.01100	+.00829	+42.976
11	.01103	.01260	-.00157	-14.234
Total	.2838	.28379		
Total Relative Error			+.00001	-67.397
Average Relative Error				- 6.127
Total Absolute Error			.05949	264.589
Average Absolute Error			.00541	24.054

Table 14. Comparison Between Adjusted Film Times and MTM Times

Ele. No.	Adjusted Film Times	MTM Times	C_{mi} = Fi-Mi	%C = $\frac{Fi-Mi}{Fi}$ x 100
1	.01996	.02712	-.00716	-35.872
2	.01696	.01560	+.00136	+ 8.019
3	.01177	.02070	-.00893	-75.871
4	.03007	.02394	+.00613	+20.386
5	.01237	.01530	-.00293	-23.686
6	.03151	.02340	+.00811	+25.738
7	.01158	.02154	-.00996	-86.010
8	.01672	.01038	+.00634	+37.919
9	.03122	.02226	+.00896	+28.700
10	.01386	.01020	+.00366	+26.407
11	.00793	.01350	-.00557	-70.240
Total	.20395	.20394		
Total Relative Error			+.00001	-144.510
Average Relative Error				- 13.137
Total Absolute Error			.06911	438.848
Average Absolute Error			.00628	39.895

Table 15. Comparison Between Adjusted Film Times and Work Factor Times

Ele. No.	Adjusted Film Times	Work Factor Times	C_W = Fi-Wi	%C = $\frac{Fi-Wi}{Fi}$ x 100
1	.01409	.018000	-.003910	-27.750
2	.01197	.014150	-.002180	-18.212
3	.00831	.012675	-.004365	-52.527
4	.02122	.021850	-.000630	- 2.969
5	.00873	.007200	+.001530	+17.526
6	.02224	.021675	+.000565	+ 2.540
7	.00817	.008700	-.000530	- 6.487
8	.01180	.011650	+.000150	+ 1.271
9	.02203	.016950	+.005080	+23.059
10	.00978	.004800	+.004980	+50.920
11	.00559	.006300	-.000710	-12.701
Total	.14393	.14395		
Total Relative Error			-.00002	-25.330
Average Relative Error				- 2.303
Total Absolute Error			.024630	215.962
Average Absolute Error			.002239	19.633

Table 16. Summary of Results

System	Standard Deviation of Errors σ_E (Mins)	Standard Deviation of Percent Errors $\sigma_{\%}$	Average Absolute Error $\frac{\sum(Ci)}{11}$ (Mins.)	Average Absolute Percent Error $\frac{\sum\left(\frac{Ci}{Fi}x100\right)}{11}$ (%)	Average Relative Percent Error $\frac{\sum\left(\frac{Ci}{Fi}x100\right)}{11}$ (%)
BMT	.00703	33.283	.00541	24.054	-6.127
MTM	.00715	47.051	.00628	39.895	-13.137
Work Factor	.00306	27,303	.00224	19.633	-2.303

to the film cycle.

The standard deviation of the errors between the elements of the adjusted film cycle and the Work Factor cycle was much less than that incurred between the adjusted film cycle and the other two synthesized cycles. This result indicated that there was generally a better degree of internal consistency between the elements of the adjusted film cycle and those derived by Work Factor than between the other two pairs of data. The standard deviation of the errors incurred between the adjusted film cycle and the BMT cycle was very near but slightly smaller than that incurred between the film cycle and the MTM cycle.

The same general pattern was found with the standard deviations of the per cent errors, that is, the lowest was found with the Work Factor cycle, the next with the BMT cycle and the highest with the MTM cycle. There was, however, a more pronounced difference between the standard deviations of BMT and MTM and less between BMT and Work Factor than was found in the case of the errors, indicating that relative to the magnitude of the film time, BMT and Work Factor were fairly consistent in their agreement. In the case of the errors, Work Factor was apparently much better than the other two, BMT and MTM being fairly close together.

It seemed to be implied by the results that some degree of correlation might exist between the magnitude of the element and the magnitude of the error. In an attempt to determine the existence of such a relationship, graphs were plotted of these values for each system, both in time and percentage units. These appear in Figures 14 through 19 in the appendix.

The scattergrams of the values gave only a slight indication of a positively sloped line but the results were inconclusive. Consideration was given to the calculation of correlation coefficients for the values but it was felt from the graphic results that other tests would yield more conclusive results.

<u>t Test</u>.--The elemental film times were actually derived from a rather large body of film values and were obtained by calculating the mean of the elements of forty selected cycles of the operation in question. In other words, the film values used for the analysis were actually mean values.

Time values obtained from synthetic time study should theoretically produce only one time value for any one given set of conditions. The originators of the various systems claim by both direct statement and implication that the results by an individual fully qualified in the use of a particular system will be correct, and that there will be little, if any, difference in the results obtained by various qualified analysts. Human failing, however, probably causes some unknown amount of error in analysis results. These errors can probably be minimized when analyses are made only by individuals highly experienced and trained in the application of the particular system being considered. In this study each analysis was made by an expert in the use of the particular system being considered. Therefore, it was assumed that the standard data times obtained by each system were correct values representative of universe mean times for the operation performed in the standard manner. It was therefore possible to test the hypothesis that the film times could have come from a population with a true mean corresponding to the system times. This was done by use of the students t test.

The value of t is defined as being the ratio:

$$t = \frac{\mu - \bar{x}}{s/\sqrt{n}}$$

where $(\mu - \bar{x})$ is the difference between the sample mean and the expected value, s is the standard deviation of the distribution of values where mean is $\bar{x}$ and n is the number of observations included in $\bar{x}$.

The deviations between the elements of the adjusted film cycles and the standard data cycles ($\mu - \bar{x}$ in this test) were previously calculated and appear in Tables 13, 14, and 15. The variances of the forty cycles from which each element mean time was computed appear in Table 8. The deviations were determined between the elements of the standard data cycles and the adjusted mean film values and the variances were calculated of the forty film times from which the unadjusted mean film cycle was derived. Therefore, in order to use the previously computed variances in the t test in conjunction with the afore described value of $(\mu - \bar{x})$, it was necessary to multiply the elemental variances by the same adjustment factor that had been used for the mean element time.

The values of t for each element and each system were calculated and appear in Table 17.

By consulting the proper table of t values, it was found that for an $\propto$ error of 5% and 40 degrees of freedom*, the value for t was 2.02. The majority of the calculated values of t were larger than the value found in the table which indicated that for those particular ele-

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*Actually the correct number of degrees of freedom would have been n - 1, or 39, but limitations of the table made it more convenient to use 40.

Table 17. Summary of t Values

Element Number	Element	BMT	MTM	Work Factor
1	Get barrel.	6.760	20.493	15.853
2	Place barrel.	6.603	3.282	7.454
3	Get writing unit.	15.806	14.632	10.162
4	Place writing unit.	6.922	6.067	.882*
5	Get drive nut.	.378*	4.826	3.572
6	Place drive nut.	.720*	10.427	1.040*
7	Get ferrule.	4.787	19.033	1.432*
8	Place ferrule.	5.524	6.542	.219*
9	Get and place assembly.	7.165	12.187	9.766
10	Stake.	23.302	14.290	27.632
11	Remove, give left to right.	4.138	20.483	3.680

* Not significantly different from the film average time value.

ments, the probability of the two values being tested having come from the same normal population was less than .05. In only six cases were the calculated values of t smaller than the corresponding table value*. Two of the six cases were found in BMT and four in Work Factor. None of the values from the MTM systems indicated that the two figures being tested could have come from the same normal universe.

The t values were either rather large or rather small, indicating that there was either a rather significant deviation or very little deviation between the adjusted mean film times and the synthesized times. For an α error of 1% or of 10% the results would have been the same as those reported above.

These results seemed to imply that the users of the standard data systems either accurately measured the time for the given sequence of motions included in the elements or made a rather poor estimate, with a clear-cut distinction between the two. This could possibly be attributed to the type of basic elements used in the standard data systems or to the type of research used in the formulation of the systems. The writer considered the effect noteworthy but would hesitate to venture an explanation of the real cause.

Relating the results of the t test to the previously described division of the variances of the elements into "Get" and "Place" categories, it was perhaps significant that of the six cases which indicated less than significant deviation, four were "Place" elements and two were "Get" elements. There was, however, very little consistency between

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*The calculated t values which were smaller than the table value are indicated by an asterisk (*) in Table 17.

the systems concerning the less than significant deviations. In only one case did the less than significant deviations occur on the same element.

In general, the t test tended to indicate that in the majority of the synthesized elemental values differed very significantly from the mean film values, with, however, a few cases where only minor deviation was found.

Correlation Between Errors and Systems.--It was desired to test the correlation between the errors of the various systems. Since there were three pairs of errors, it was necessary to compute a correlation coefficient for each pair of errors. These results are indicated in Table 18.

The table of correlation coefficients indicated that there was a much greater probability of correlation between BMT and Work Factor than between the other two pairs of errors. The level of significance of the BMT Work Factor correlation coefficient was .01, indicating that either a true correlation did exist or a chance happening had occurred which had a probability of less than 1 in 100.

Both the BMT-MTM and the MTM Work Factor pairs of errors yielded correlation coefficients at greater than .05 confidence levels. The correlation coefficient for the MTM Work Factor pair of errors was significant at the .06 level whereas the BMT-MTM pair was significant at the .09 level.

The test seemed to indicate a general correlation between the errors of all of the standard data systems involved in the study, however, there was a much higher level of significance associated with the BMT Work Factor correlation coefficient than with the other two pairs. The same trend seemed to be prevalent throughout the entire

Table 18. Correlation Between Errors and Systems

Pairs of Errors	Correlation Coefficient	Level of Significance
BMT and MTM	.544	.09
BMT and Work Factor	.764	.01
MTM and Work Factor	.585	.06

study and was perhaps a direct reflection upon either the methods used to separate and distinguish the elements, or upon the correctness of the time data used by each system. From the above, and the previously described tests, one could only conjecture as to the true cause, however, the knowledge that two of the systems produce results which seem to correlate in various ways supplies valuable information concerning further study which might be made.

Analysis of Order of Errors.--A summary of the sign of the errors incurred by each element and each system appears in Table 19. It should be noted that a + sign indicates that the adjusted film time was longer than the synthesized time for the particular element in question. A negative sign indicates the converse.

In six of the eleven elements, all three of the systems had errors of the same sign; that is, the systems produced elemental times that were either all larger or all smaller than the adjusted film time for the elements. By means of the binomial formula, it was possible to calculate the probability of such a pattern being produced by chance alone. By summing the values of the formula over the proper range, it was found that the probability of such an occurrence happening through chance alone was approximately .03. Stated in another manner, if each sign in Table 19 had had an equal chance of being either + or -, then the pattern observed in Table 19 would have happened only about 3 times in 100 tries.

The results of this test indicated generally the same results that were observed in earlier tests. That is, there seemed to be a general correlation between the results produced by the three standard data systems in question. At least, it could be surmised that the

Table 19. Summary of Types of Errors

Element Number	BMT	MTM	Work Factor
1	+	-	-
2	-	+	-
3	-	-	-
4	+	+	-
5	+	-	+
6	+	+	+
7	-	-	-
8	-	+	+
9	+	+	+
10	+	+	+
11	-	-	-

systems produced the same type of results, although the test conducted here did not give any indication of the real accuracy of the systems.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The results of the tests conducted in this thesis offered ample evidence to prove that there is significant difference in the ability of the three standard data systems under consideration to measure the time for a short manual operation. This conclusion must, however, be qualified in the light of the limitations imposed upon the study, which were as follows:

(1) Only three standard data systems were used in the study.

(2) Only one manual operation was used as a basis of comparison.

(3) The experimental situation was developed around only one application of each system.

(4) Only internal consistency between the elements of the film cycle and the synthesized cycle was investigated.

All three of the systems indicated a general lack of agreement between the elements of the synthesized cycle and the elements of the film cycle, as was exemplified by the fact that there was an absolute deviation of 27.86%* between the synthesized element times and the film element times. (See Table 16, Chapter IV.) Considering some of the claims of accuracy of many of the founders and proponents of the standard data systems, and the results of the present investigation, one is inclined to eye the results of standard data systems with

*Based on the film time.

some skepticism.

The average absolute deviation for the three systems considered in this study was approximately 25%. As can be seen from Table 16, there was approximately a 20% range between the highest average absolute percent deviation and the lowest produced by the three systems. The least percent deviation was a result of the Work Factor system which had a 19.633% average absolute percent deviation with BMT being next having 24.05% and MTM highest with 39.895%.

It should be noted that the figures given above are in absolute units and only show the magnitude and not the direction of the deviation. In order to determine the effect produced by the magnitude and the direction of the error, the average relative percent deviation was calculated, and these figures are also shown in Table 16.*

The same general gradation was found in the average relative percent errors as in the average absolute percent errors. That is, the smallest relative percent error was found with the Work Factor system, with BMT next and MTM largest. There was approximately a 10% difference between the smallest average relative percent error and the largest as was the case with the average absolute percent errors.

It will be noted from Table 16 that all three standard data systems produced negative average relative percent errors. This means that all of the systems generally tended to produce time estimates of greater magnitude than the values found through actual film analysis of the elements.

From Table 16 it can also be seen that the standard deviations

*The experimental procedure forced the total relative error to be zero.

of the errors and the percent errors followed the same general gradation trend as did the other previously mentioned measures. That is, Work Factor produced the smallest, BMT the next and MTM the largest standard deviation indication that the greatest internal consistency was produced by Work Factor, next by BMT and the least by MTM.

From the analysis of the signs of the error incurred between the elements of the synthesized cycles and the film cycle, it was evident that there was a general correlation between the errors incurred by the three standard data systems. From this, it may be construed at least for the conditions set forth in this study, there seemed to be some mutual system in the results of the three standard data systems. This might be due to the basic data itself, or the method of application, or both.

More specifically, from the foregoing statements, it was concluded that:

(1) There was better agreement between the elements synthesized by Work Factor and the measured elements of the film cycle than was true with the other two standard data systems under consideration.

(2) All of the three systems under consideration generally produced time estimates of the elements which were larger than the actual elemental times derived from film analysis.

As a by-product of the analysis, it was found that, at least for the particular case at hand, there was strong suggestion of a systematic difference in the variances of the various elements, affected by the type or possible degree of complexity of the elements. Even though the present study is not designed to yield positive results concerning this matter, the fact that a rather common manual operation was used as a vehicle of the study would lead one to believe that the same condition might be found in other operations. Further study in this direction might uncover fruitful information concerning the relationship between the degree of complexity and the variances of various elements of work. In this direction it might be wise to test the hypothesis:

> The variance of an element of manual work increases as the degree of complexity of the element increases.*

As was previously brought out, there is a possibility that the magnitude of the variance of elements of manual work might vary systematically with some variable which has not been considered. Therefore, in future analysis concerning this matter, precautions should be taken to determine the possible existence of such a relationship.

It was not the purpose of this thesis to substantiate or refute the basic validity of the standard data technique. It is felt, however, that the procedure outlined in this thesis and the results attained are a step toward quantitative evaluation of the results of various standard data systems. It would be interesting to note the results of the same type of analysis when applied to other types of manual operations, other applications and other methods of time measurement.

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*This hypothesis is similar to the one investigated by George Forrester, A Statistical Analysis of Some of the Causes of Timed Variance in Stop Watch Time Study, unpublished Master of Science Thesis, Georgia Institute of Technology, 1953.

APPENDIX

Table 20. Summary of Variations Found
Films X1 - W23

A	Unscrew drive nut before dispose units. (Hold both units left hand, unscrew units right hand.)
A_1	Unscrew only one drive nut. (Held in separate hands.)
A_2	Unscrew both drive nuts. (Held in separate hands.)
B	Give left completed unit to right hand and keep.
C	Give left completed unit to right hand then dispose all units.
D	Difficulty placing barrel in jig.
E	Difficulty placing completed unit in stake hole.
F	Remove completed unit from stake hole and try in other stake hole.
G	Difficulty placing unit in barrel.
H	Adjust completed units.
I	Get supply drive nuts.
J	Get supply ferrules.
K	Get supply barrels.
L	Difficulty aligning drive nut.
M	Attempt to insert wrong end ferrule, then turn.
N	Attempt to insert wrong end unit, then turn.
O	Attempt to insert wrong end barrel, then turn.
P	Overhand pick up barrel.
Q	Overhand pick up of unit.
R	Pick up bad or completed unit, aside and pick up another.
S	Pick up unit from other than unit tray.

Table 20. Summary of Variations Found (Continued)
Films X1 - W23

T	Re-stake unit.
U	One hand help other place ferrule.
V	Fumble pick up unit.
W	Fumble pick up ferrule.
X	Remove completed units from dispose tray before pick up barrel.
Y	Remove completed unit from barrel tray before pick up barrel.
Z	Remove and replace ferrule before stake.
a	Fumble insert barrel.
b	Fumble pick up completed unit from jig.
γ	Fumble pick up barrel.
d	Hold and inspect completed units before aside (after stake).
e	Fumble dispose completed unit (transfer hands).
f	Unusual delay - cause unknown.
g	Interference from some other person (on pick up unit or barrel).
h	Pick up and dispose bad drive nut.
i	Difficulty inserting ferrule.
j	Turn ferrule before insert.
k	Fumble assemble ferrule.
l	Turn drive nut after place ferrule.
m	Pick up two barrels one hand, insert one, replace other.
n	Pick up drive nut from other than tray.
q	Fumble insert unit.
r	Dispose units after insert barrel.

Table 20. Summary of Variations Found (Continued)
Films X1 - W23

t	Remove completed unit from ferrule tray after insert barrel.
u	Reach one tray, change mind and reach another tray.
v	Inspect completed units in dispose tray.
w	Pick up barrel tray, dump and dispose tray.
y	Tap completed units on table after stake.
z	Tap completed units on table after insert barrel.
α	Dispose completed units after insert ferrule.
β	Give all completed units to left, loosen all nuts with right.
δ	(See W18, cycle 3)
ϵ	Pick up barrel and unit, toss out unit and replace.
$\ni$	Lose ferrule while T. L. to stake, stop and replace.
a_1	Adjust units in tray while pick up unit.
a_2	Aside defective completed unit.
a_3	Adjust barrels.
a_4	One hand pick up one object while other hand another.
a_5	Fumble pick up drive nut.

Table 21. Position of all Variations from the Standard Cycle

Cycle No.	Film Numbers										
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	W11
1	A	A	A	G	A	G		A		A	B
2		A	A	ATY	A	AH	AfHV	A γ			Bz
3	ADE	AE	A			SV	AIJK	A	V	G	A_1Bz
4		AL	AW	A		U	A		AH	N	A_2Cyz
5	AEG	A	ADY	AW	G	dJY	AGg		G	AZ	A_1C
6	AH	A	AV	AL	W		A			AG	A_1Bb
7	A	AE	A			E	O			AI	A_1Bz
8	A	A	AIZ	Ab		A	A	A	A	Q	A_2Ciy
9		ANR	A			Y	A	A		Q	A_2BK
10	A	A	A			I				AH	BPy
11	AI	AG	Aa		γ	d	A	A	A		A_1Bz
12			AN				Ad	AM	Ad		A_1CQ
13		AL	AW	A			Ad	A	A	AZ	A_2BZ

Table 21. Position of all Variations from the Standard Cycle (Continued)

Cycle No.	Film Numbers										
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	W11
14	A	AL	AW	FW			AdT	A		A	B
15	AEIM	S	I	G			Ad	Ai		AN	A_1Bz
16	D	A	AQ			AD		A	A		A_2Cyz
17		AT	A			e	h	Ai	V	A	A_1BW
18		AG	A	I			____	A	S		A_1B
19		IJ	A	A_1G_1	AL			A			B
20		AU	A		AG	f		AQ	A	AN	A_1Cz
21	A		AG		A____			A	d____	Aj	$A_1$1B
22		V____	L____					A		A	BWz
23								G____		A____	Dz____
24	____					A____					
25											
26				____							

Table 21. Position of all Variations from the Standard Cycle

Cycle No.	Film Numbers W12	W13	W15	W16	W17	W18	W19	W20	W21	W22	W23
1	B	A_2Bz	B	B	BQy	B	B	BH	A_1B	A_2Cy	A_1BHz
2	B	Bz	B	A_2B	By	A_2BMy	A_2B	A_2ByZ	A_2By	A_2BP	A_2Bz
3	A_2B	Bz	BM	B	Bα	Cyδ	BN	Bz	A_2Cyz	A_2a_5By	A_3BQ
4	CLyz	Cyyz	A_3Cyz	A_2CP	B	A_2BQ	B	By	A_2BP	A_2By	BQWz
5	B	B	A_1Bv	Bi	B	B	By	Bpy	B	A_1BNy	Cz
6	BXm	Bz	A_2Bw	A_2B	BV	Bu	A_1Br		A_2a_2B	A_2Cy	B
7	B	Biz	CIJy	A_3CGy	Cβz	BMP	A_2By		Bnyz	A_2BMn	A_2BM QWz
8	A_2Cyz	A_1Bz	A_2BP	A_2B	B	A_2By	A_2By		BPy	A_2B	Bz
9	A_2C	A_2ryy	A_2Byz	A_2B	B	A_2Br	By$\ni$		CPy	BGy	BSyz
10	B	A_1Btz	CWyy	By	B	A_2Bϵ	A_2Be		A_2C	A_2Cy	C
11	Bz	A_2Hru	BG	A_2B	A_2Cy	B	A_2BH		$A_2a_3a_4$ Bu	BQ	A_1BQ
12	A_2Cyz	A_2B	B	A_2By	BH	A_2By	A_2a_1B i y		A_2a_5B y$\ni$	Bz	A_1B

Table 21. Position of all Variations from the Standard Cycle (Continued)

Cycle No.	Film Numbers									
	W12	W13	W15	W16	W17	W18	W19	W20	W21	W22	W23
13	A_2B	A_2BPz	B	Br	B	A_2CV	A_2By		BMPuV	A_2BPy	A_2B
14	A_2Bn	A_2Bz	A_3Cdy	B	A_1B	BH	A_2a_2B		$A_1BQ\gamma$	A_1Bd	Byz
15	A_2Byz	By	B	B	BZ	B	A_2Cy		BQr	BP	A_2G
16	BPyz	A_2Cyyz	B	By	Cy	A_2BIMu	A_2B	A_2B	A_2B	A_2BPy	A_2BQ
17	Cqyz	A_2B	B		B	A_2By	A_2B	zZ	Bf	A_2B Myz	B
18	B	A_2Bz	A_1BHK Mry		A_2BQP	A_2Cy			Bfy	B	BQyz
19	BQ	A_2Cjyz			A_2By	A_2B			A_2CVy	A_2CPy	BNV
20	Bz	B			By	BP			A_2a_1B fQP		
21	CQyz	A_2Bz			A_2Cy	A_2By					
22	KN	A_2BQy			A_2BG						
23		P									

Table 22. Elemental Film Values

	1	2	3	4	5	6	7	8	9	10
1	.01250	.01400	.01150	.01150	.01500	.01150	.01200	.01500	.01300	.01350
2	.01050	.01050	.01050	.01100	.01200	.01150	.01300	.01100	.00950	.00850
3	.00700	.01450	.00700	.00700	.00650	.00750	.00700	.00650	.00700	.00700
4	.01700	.02000	.02450	.02600	.01450	.01650	.01850	.02100	.02200	.02050
5	.00800	.00650	.00950	.00700	.00900	.00600	.01900	.00650	.00700	.00700
6	.02350	.01950	.02600	.02250	.02200	.02050	.02750	.01900	.01750	.01850
7	.0080	.01350	.00750	.00700	.00950	.00750	.00650	.00700	.00800	.00600
8	.01400	.01300	.00900	.00700	.01050	.00650	.00850	.01050	.00900	.00850
9	.01950	.01850	.01800	.02050	.02000	.02150	.01900	.02650	.01850	.02750
10	.00750	.00950	.00850	.00950	.01300	.01050	.01050	.01000	.00850	.01000
11	.01150	.00500	.00600	.00550	.00550	.00500	.00550	.00550	.00550	.00550
Total	.13900	.14450	.13800	.13450	.13750	.12450	.14700	.13850	.12550	.13250

Table 22. Elemental Film Values (Continued)

	11	12	13	14	15	16	17	18	19	20
1	.01200	.01600	.01400	.01400	.01350	.01250	.01400	.01300	.01200	.01350
2	.01050	.01200	.01150	.00900	.01000	.01000	.01100	.01150	.01150	.01450
3	.00650	.00650	.00550	.01500	.00700	.00750	.00750	.00800	.00700	.00600
4	.01950	.01900	.02400	.02450	.02000	.01900	.01600	.01550	.01450	.01450
5	.00950	.00750	.01200	.00650	.00750	.00850	.00650	.00650	.00850	.01150
6	.02300	.02550	.02250	.02900	.01550	.02000	.02200	.02200	.01850	.01750
7	.00700	.00700	.01350	.00900	.00900	.00550	.00700	.00600	.01350	.00800
8	.00900	.01950	.00850	.00750	.00700	.00800	.01550	.01100	.01050	.00950
9	.02150	.01850	.02600	.02600	.02200	.02300	.01850	.01700	.01800	.01950
10	.00950	.00950	.01000	.01000	.00850	.00700	.01050	.01050	.00950	.00950
11	.00500	.00550	.00550	.00500	.00550	.00600	.00500	.00400	.00450	.00450
Total	.13300	.14650	.15300	.15550	.12550	.12700	.13350	.12500	.12800	.12850

Table 22. Elemental Film Values (Continued)

	21	22	23	24	25	26	27	28	29	30
1	.01300	.01250	.01300	.01150	.01550	.01350	.01300	.01700	.01400	.01300
2	.01150	.01600	.01700	.01150	.01350	.01000	.01100	.01200	.01500	.01050
3	.00700	.00750	.00800	.01450	.00800	.00600	.00650	.00650	.00750	.00550
4	.01750	.02350	.02850	.02300	.01700	.02800	.01900	.01500	.02000	.01800
5	.00750	.00850	.01300	.00700	.00600	.00800	.00550	.00750	.00850	.01050
6	.01700	.02650	.01800	.02050	.0200	.02250	.01750	.02300	.02100	.02100
7	.00550	.00500	.00650	.00700	.00700	.00650	.00750	.00650	.00650	.01200
8	.01100	.01000	.00950	.01050	.01950	.02000	.01100	.01200	.01500	.01100
9	.01950	.01750	.02250	.02100	.02350	.02050	.02350	.02350	.01900	.01600
10	.00750	.00850	.00850	.00800	.00850	.00950	.00800	.00950	.00900	.01000
11	.00450	.00550	.00500	.00450	.00600	.00450	.00600	.00450	.00550	.00500
Total	.12150	.14100	.14950	.13900	.14450	.14900	.12850	.13700	.14100	.13250

Table 22. Elemental Film Values (Continued)

	31	32	33	34	35	36	37	38	39	40
1	.01500	.01250	.01400	.01550	.01400	.01800	.01350	.01400	.01400	.01150
2	.01050	.00950	.01150	.01200	.01100	.01200	.01300	.01300	.01000	.01050
3	.00600	.01600	.00700	.00650	.00750	.00650	.01100	.00950	.00900	.01000
4	.02150	.01800	.02050	.02250	.01750	.01600	.02000	.03350	.02800	.02250
5	.01100	.01400	.00900	.00750	.00600	.00750	.00750	.00800	.00650	.00700
6	.01850	.02900	.02000	.02450	.01800	.02200	.02400	.02300	.02050	.01700
7	.00600	.00700	.00850	.00600	.01250	.00900	.00700	.00550	.00800	.00900
8	.02650	.01150	.01150	.00950	.00800	.01100	.01150	.00650	.01050	.01550
9	.01950	.01650	.02250	.02500	.02300	.02350	.02100	.02200	.01900	.02950
10	.01050	.00950	.00900	.01000	.00850	.01000	.01050	.01050	.01000	.00900
11	.00600	.00500	.00500	.00450	.00550	.00500	.00600	.00400	.00500	.00700
Total	.15100	.14850	.13850	.14350	.13150	.14050	.14500	.14950	.14050	.14850

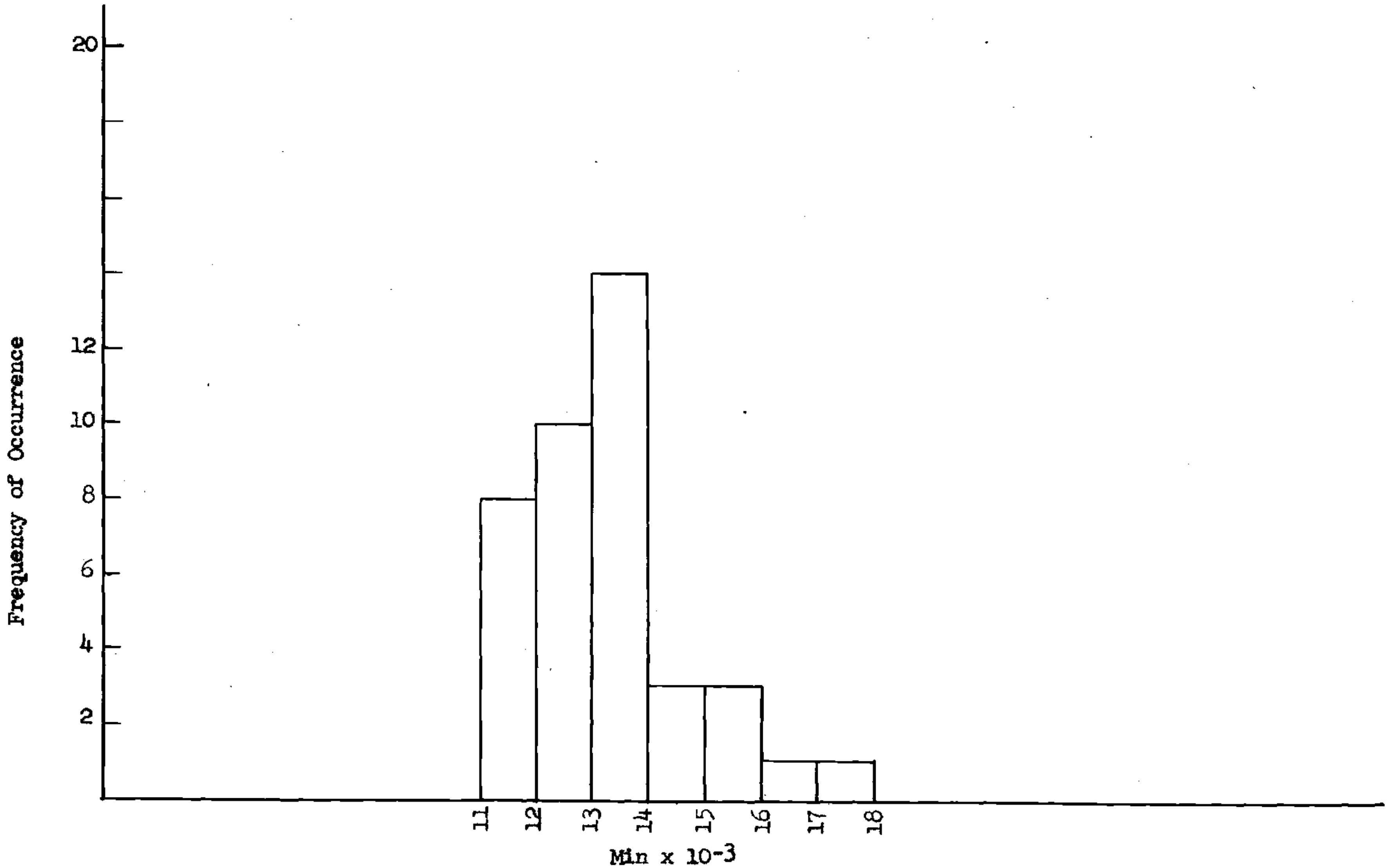

Figure 1. Frequency Disbribution of Elemental Times - Element 1

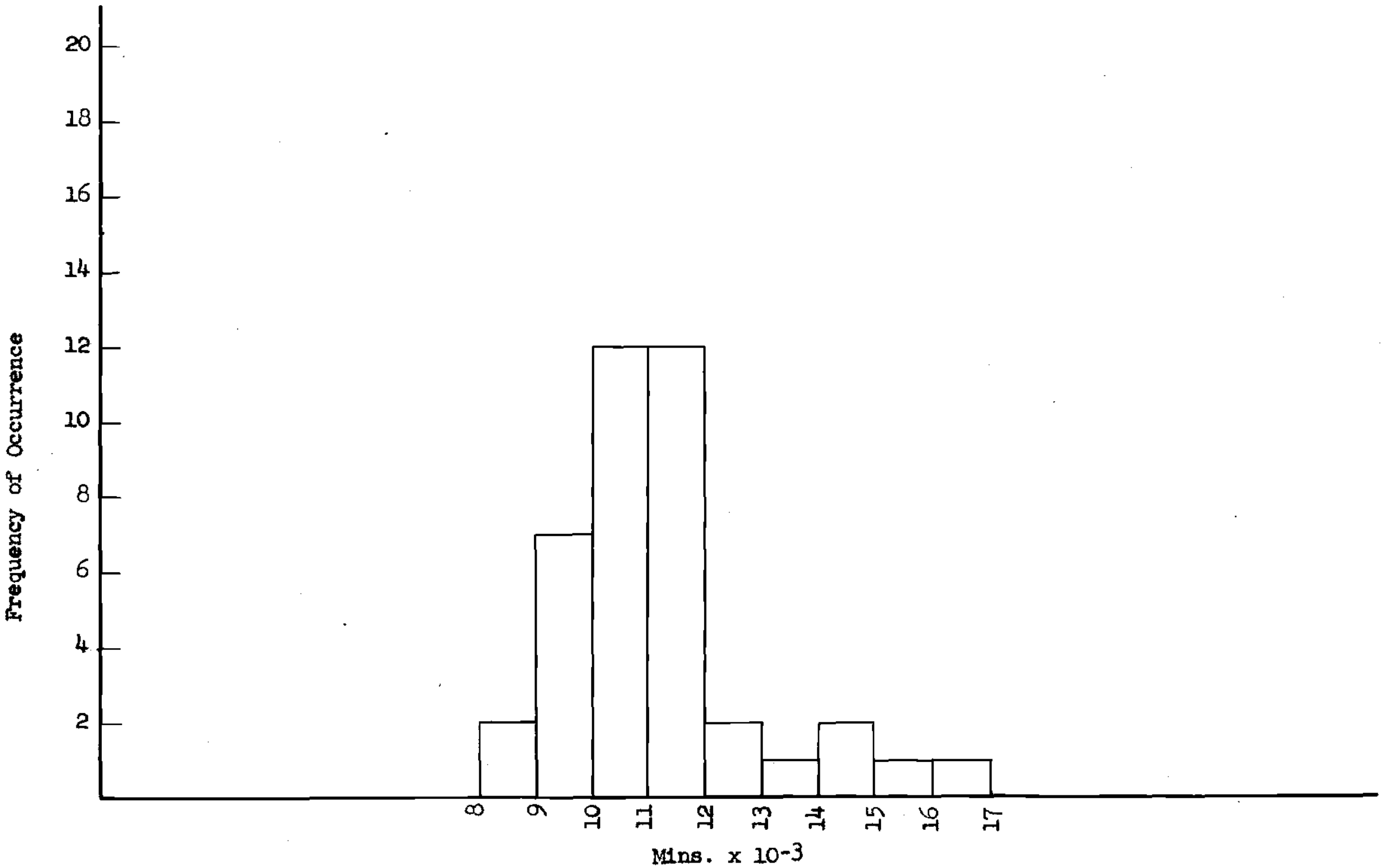

Figure 2. Frequency Disbribution of Elemental Times
Element #2

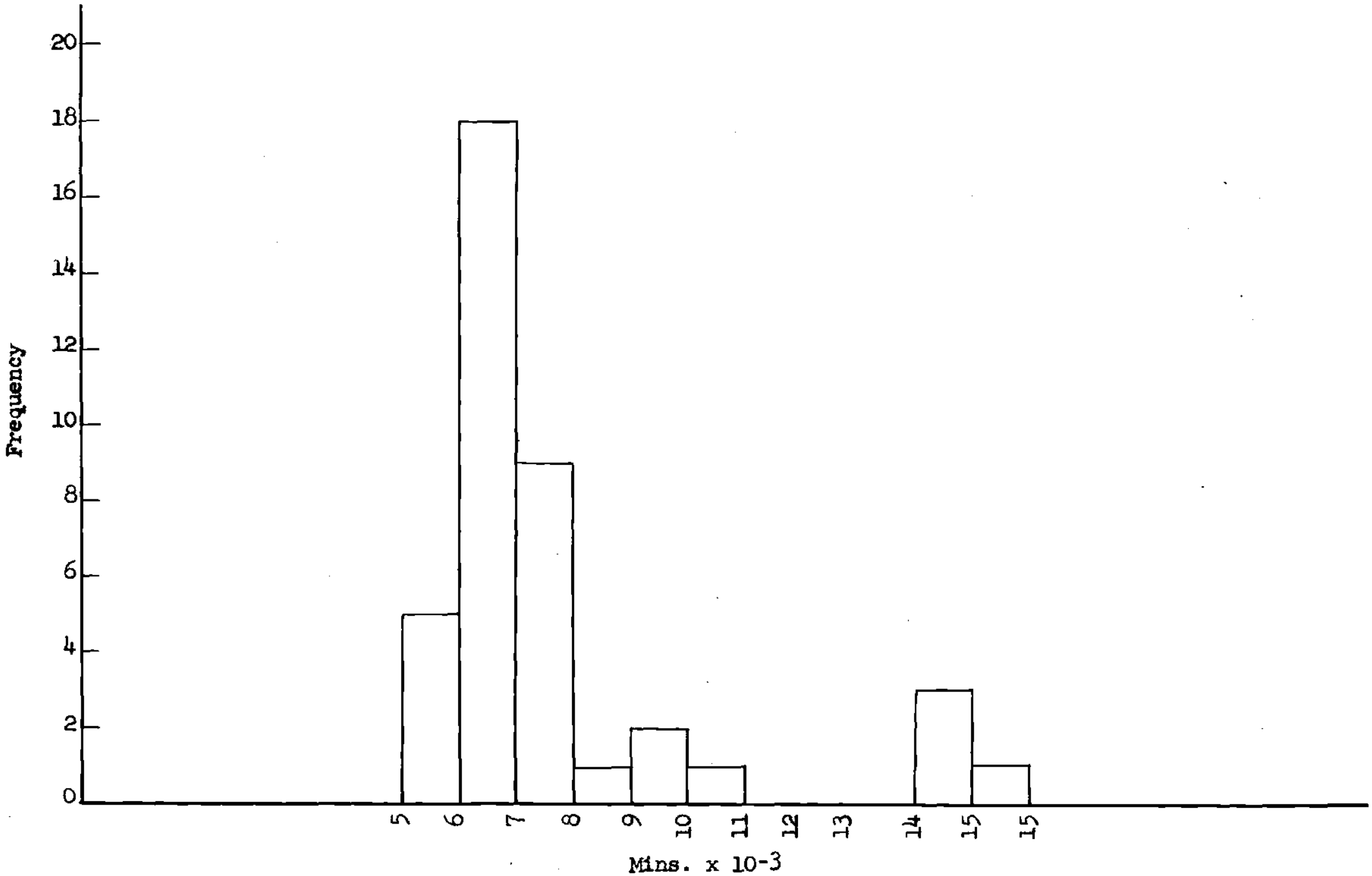

Figure 3. Frequency Distribution of Elemental Times
Element No. 3

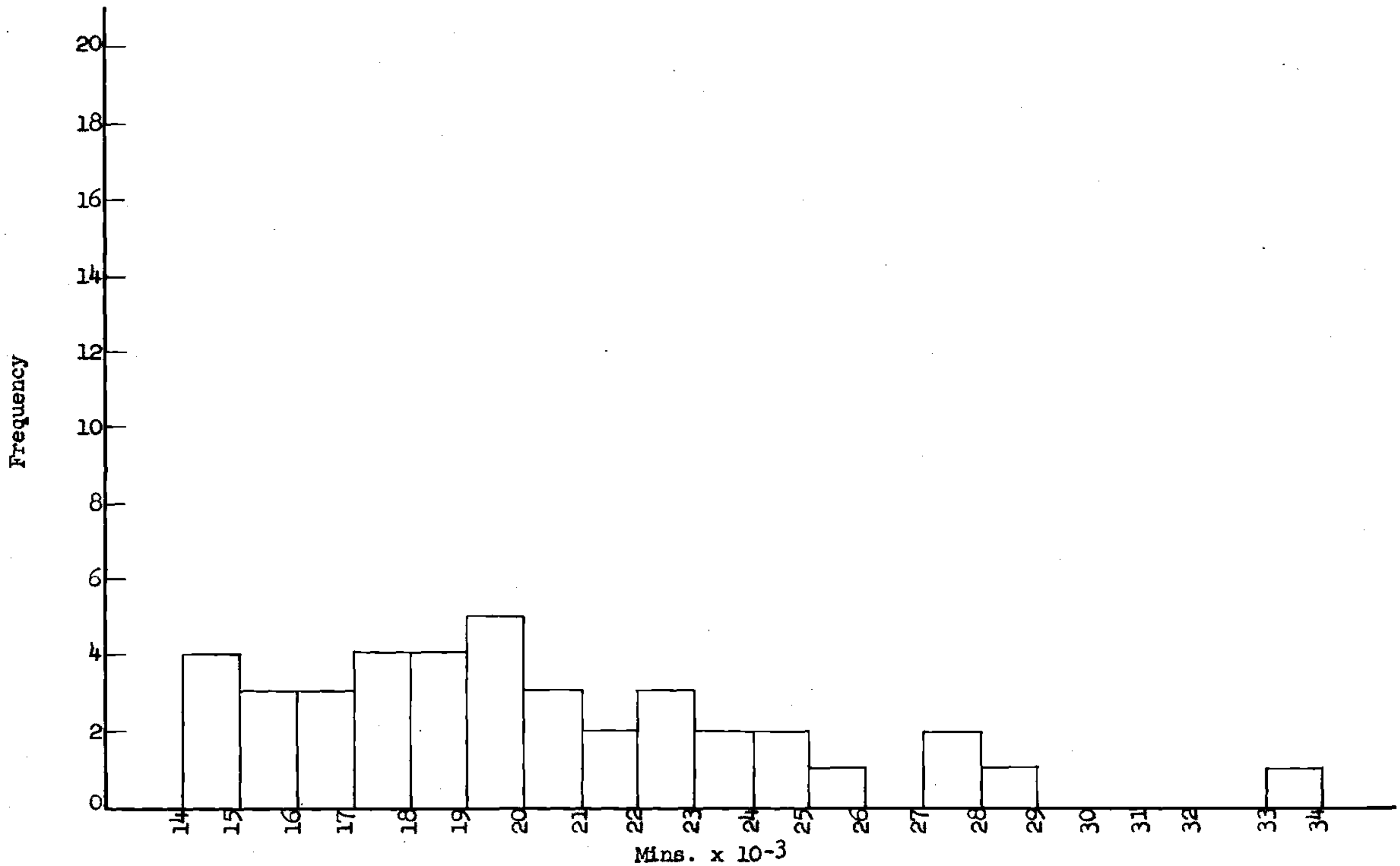

Figure 4. Frequency Distribution of Elemental Times
Element No. 4

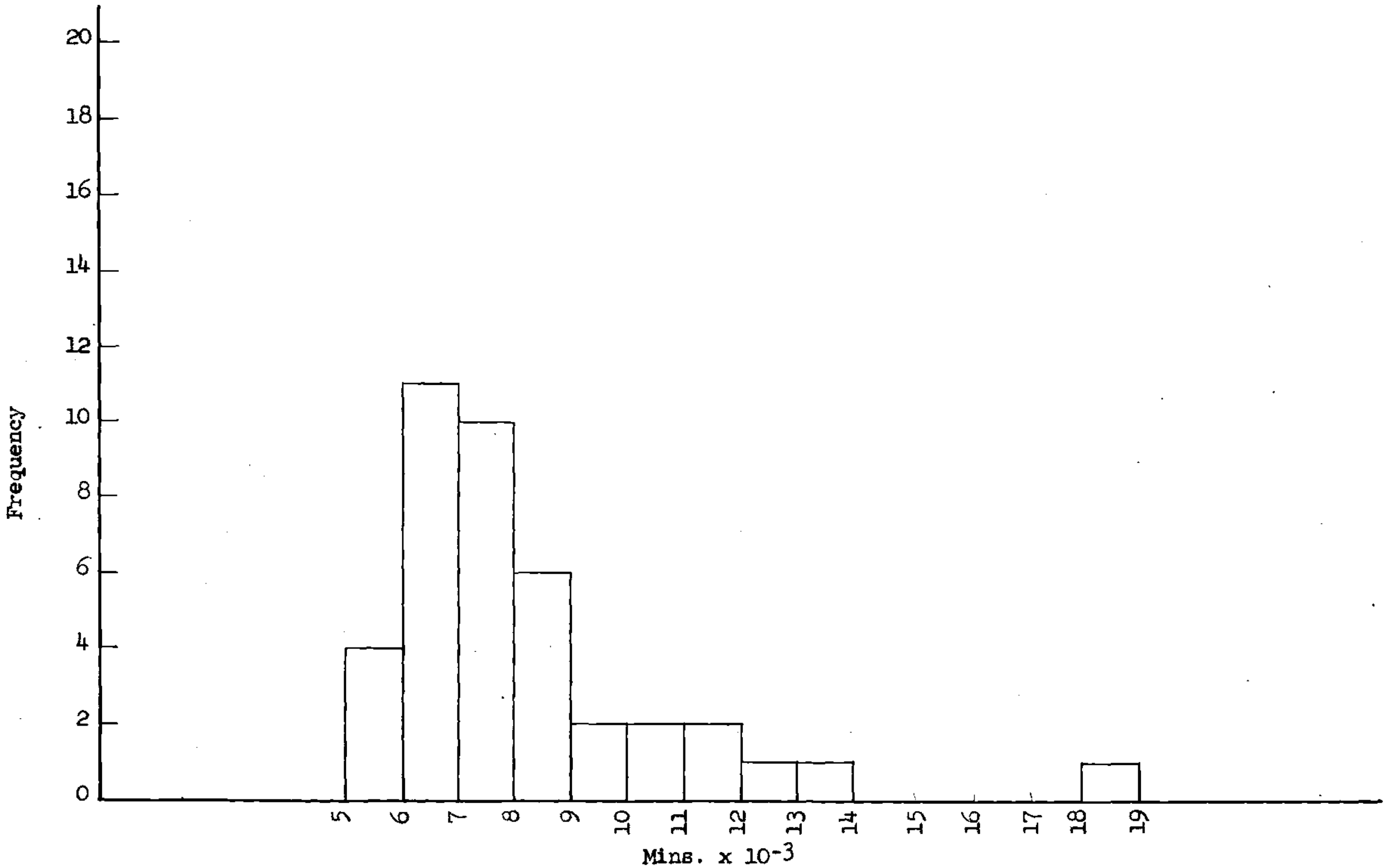

Figure 5. Frequency Distribution of Elemental Times
Element No. 5

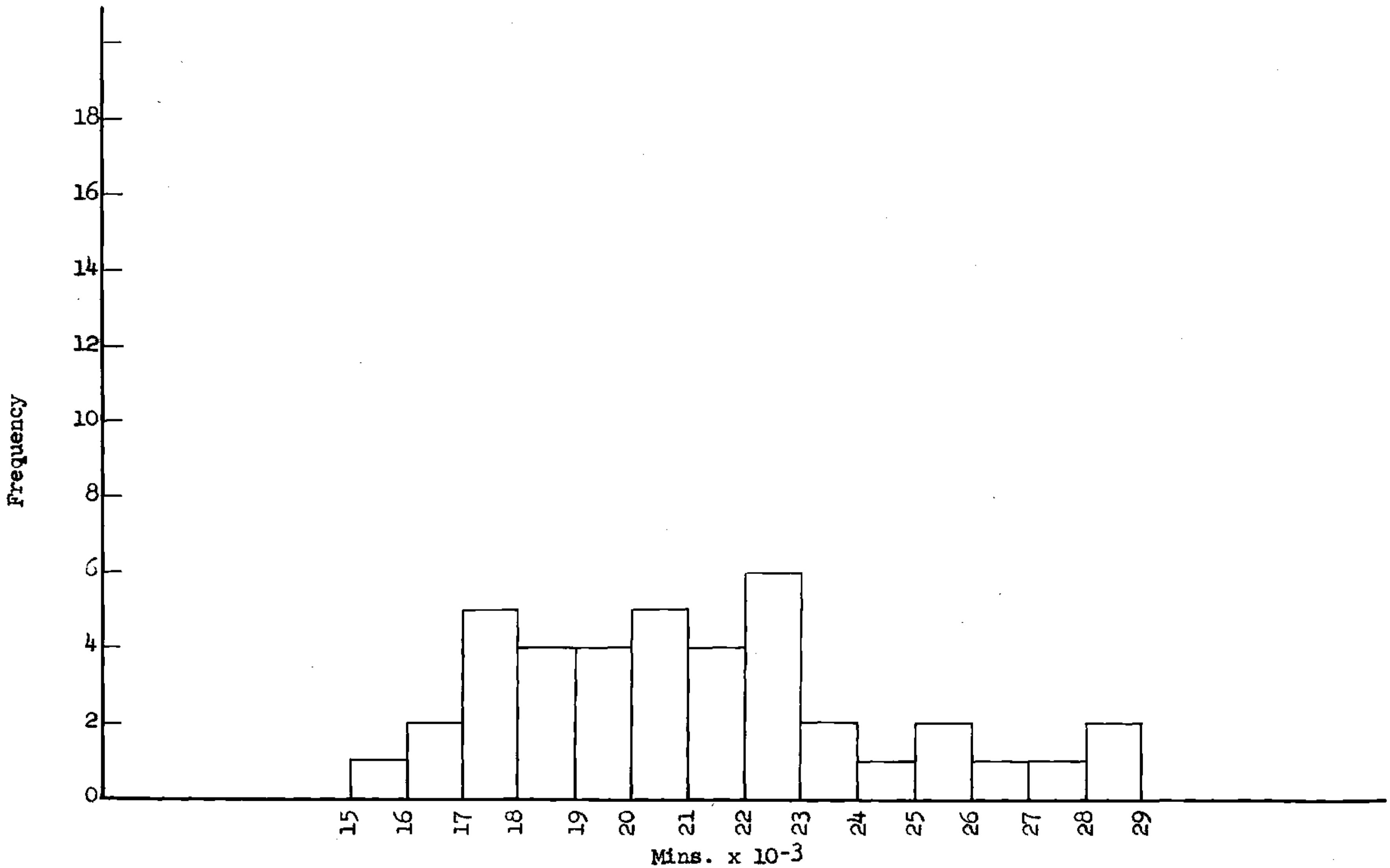

Figure 6. Frequency Distribution of Elemental Times
Element No. 6

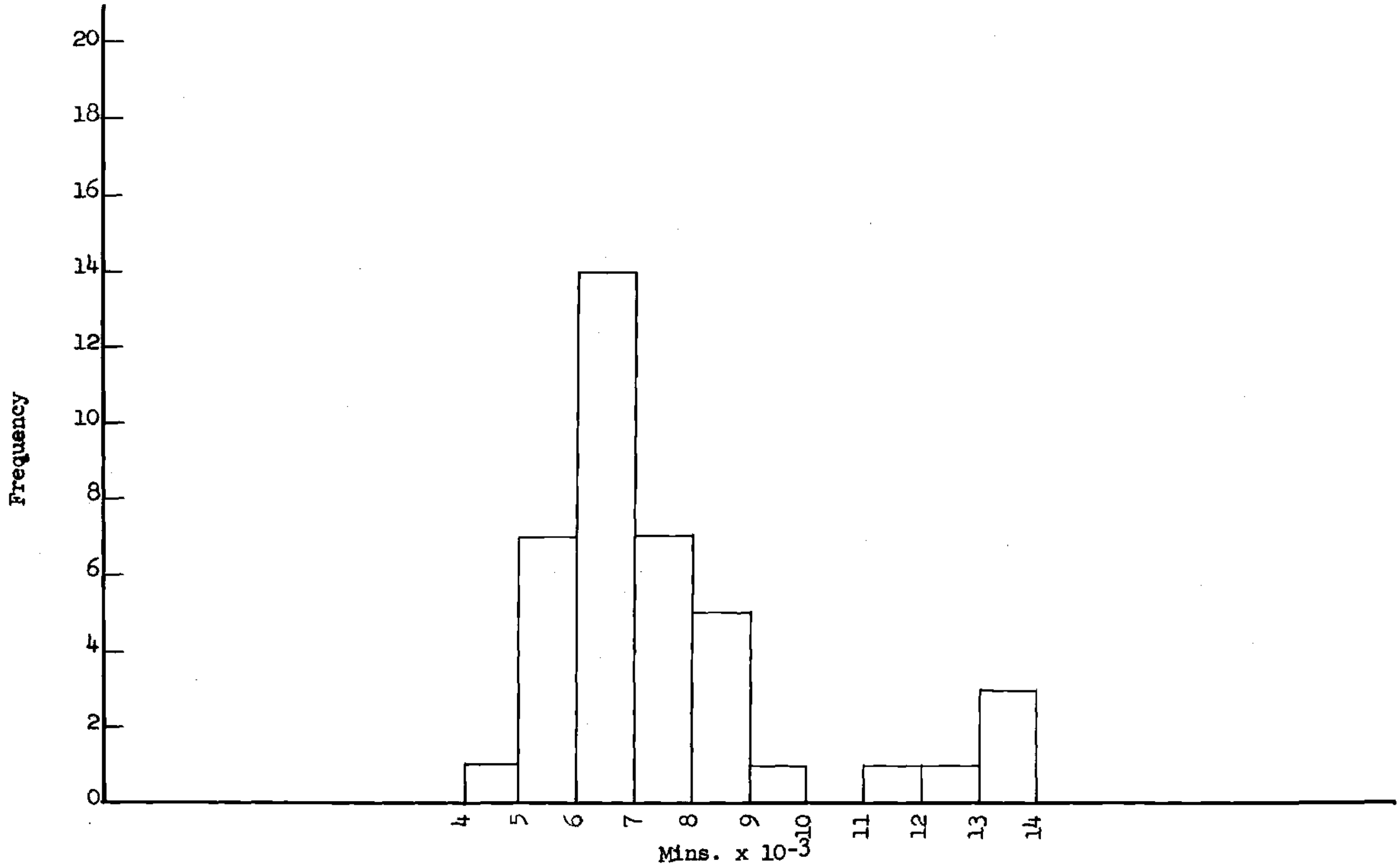

Figure 7. Frequency Distribution of Elemental Times
Element No. 7

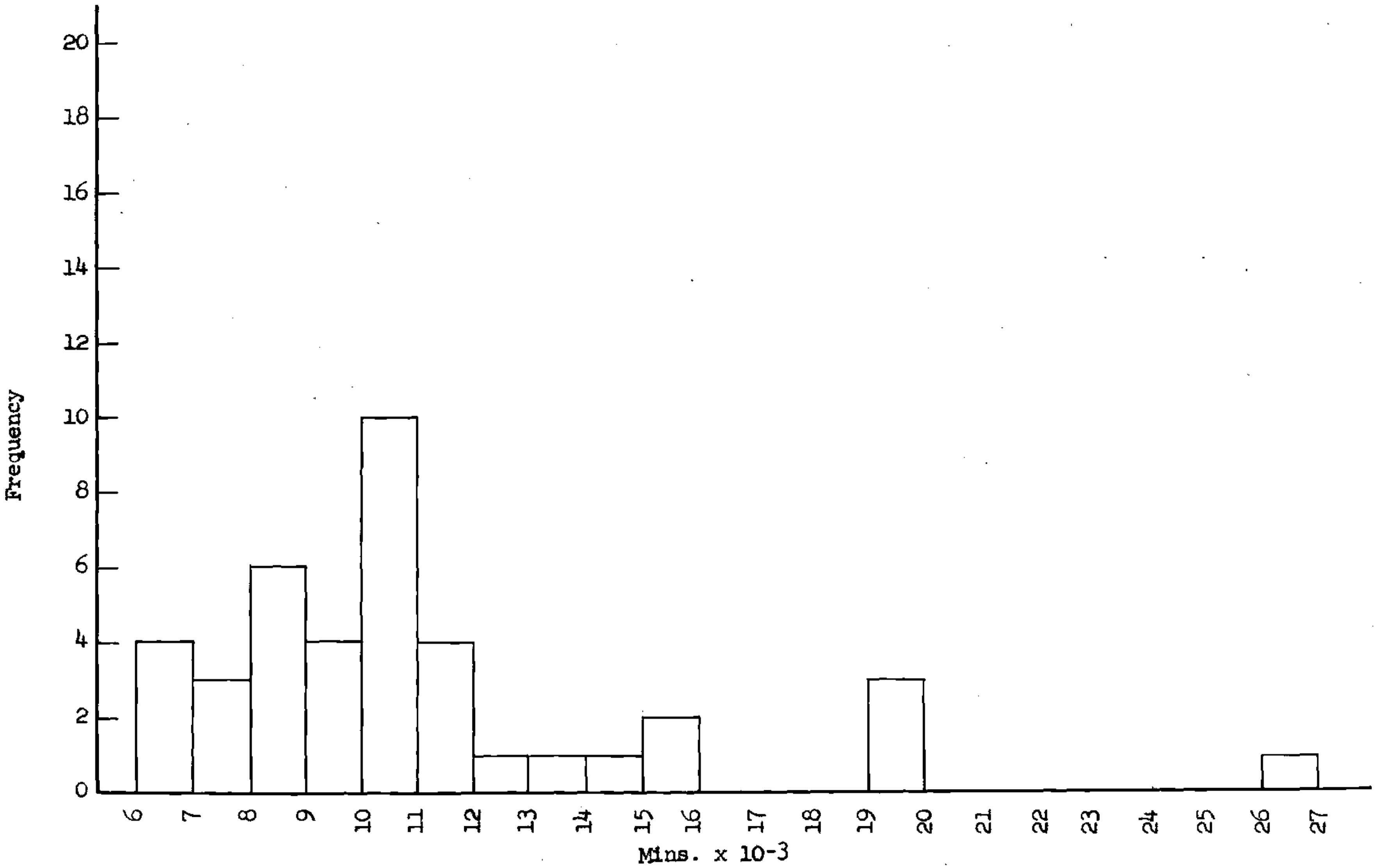

Figure 8. Frequency Distribution of Elemental Times
Element No. 8

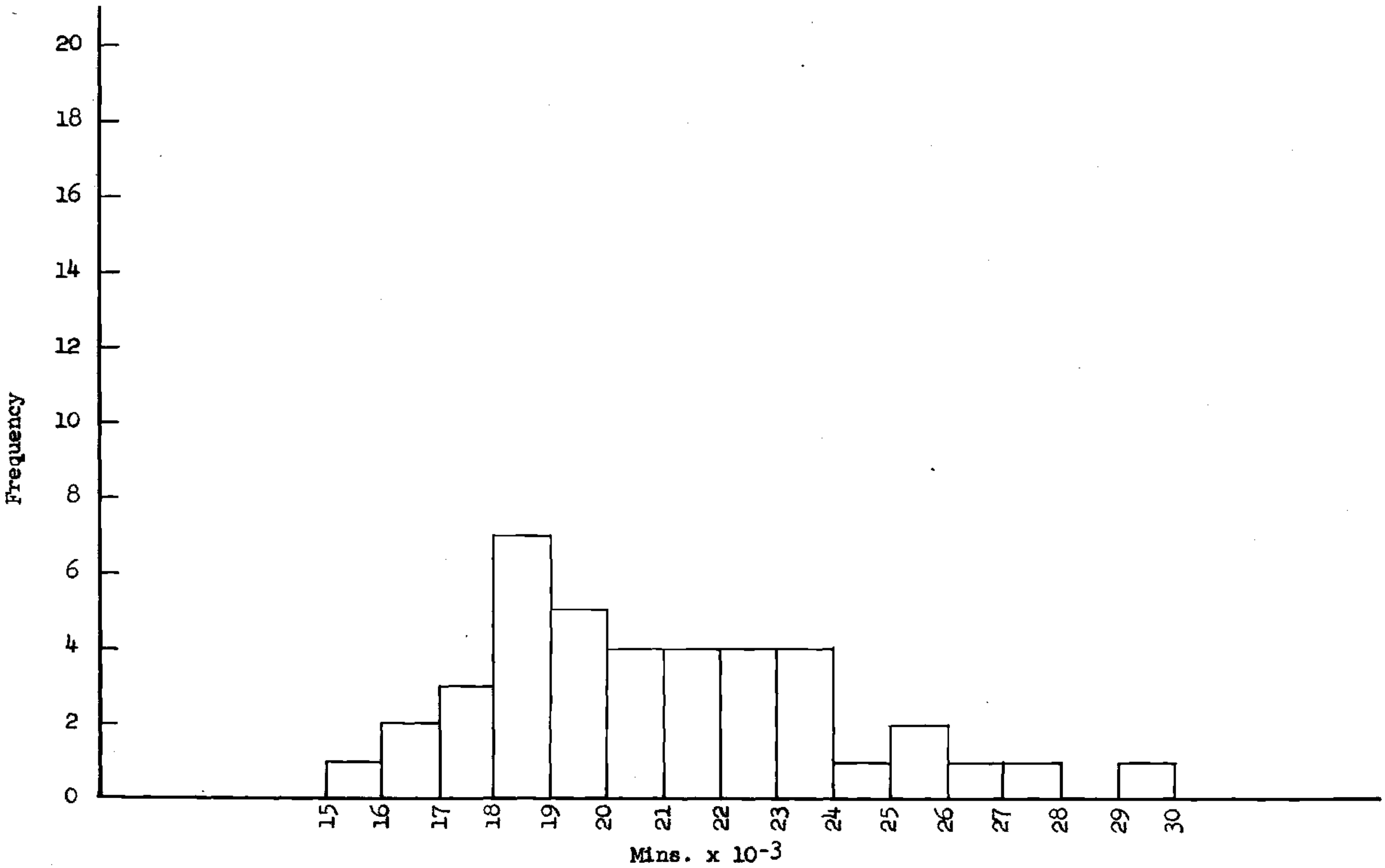

Figure 9. Frequency Distribution of Elemental Times
Element No. 9

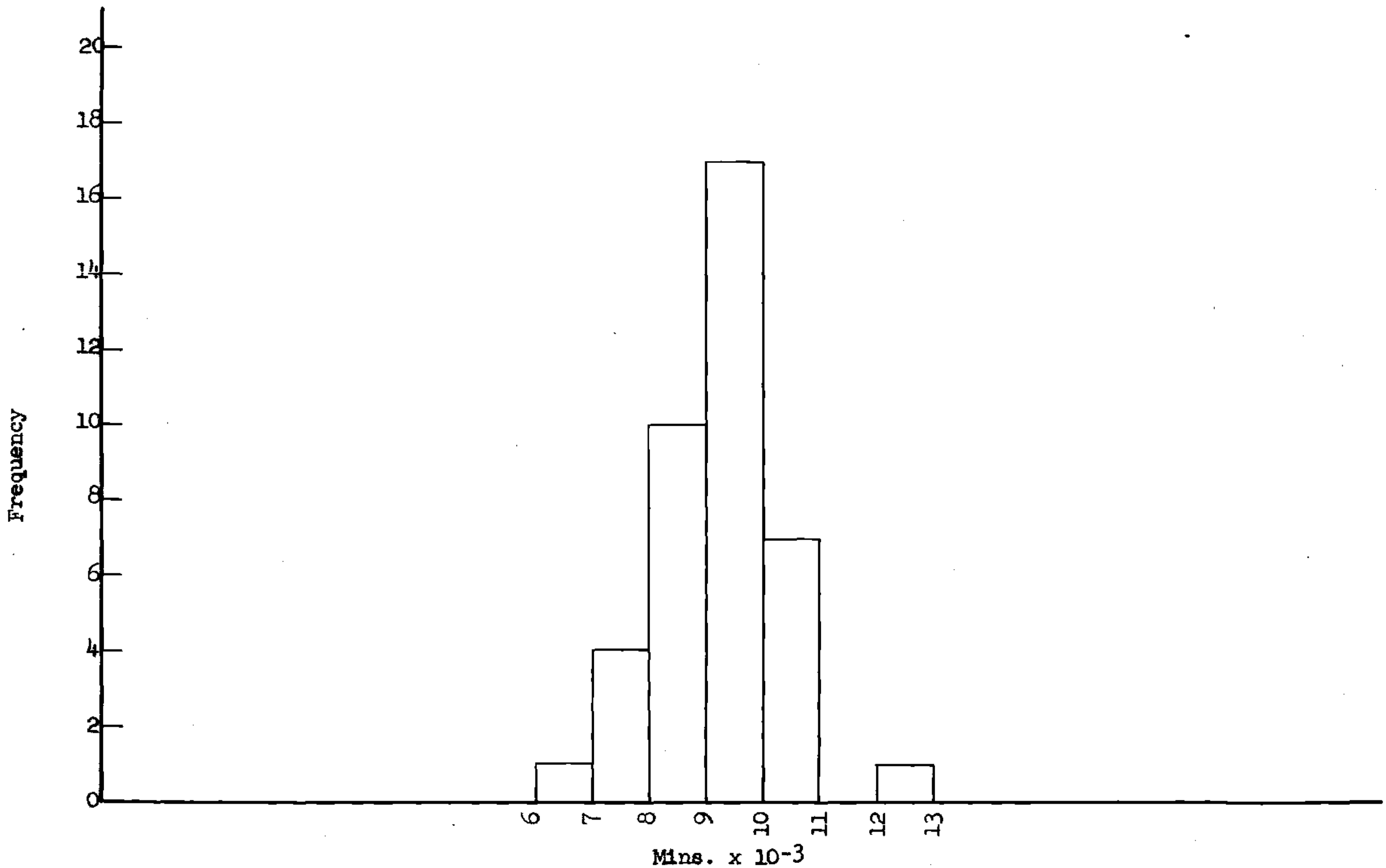

Figure 10. Frequency Distribution of Elemental Times
Element No. 10

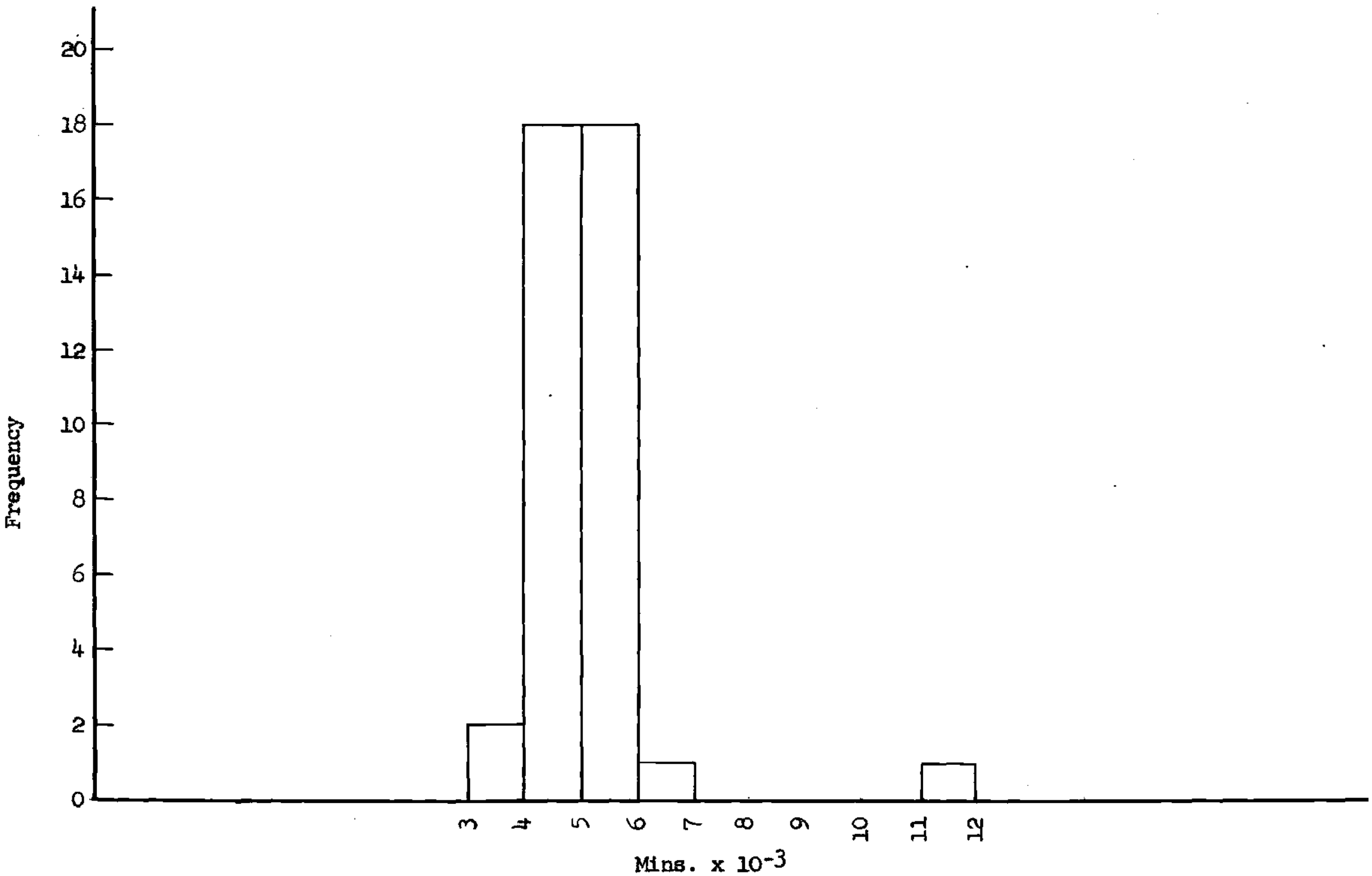

Figure 11. Frequency Distribution of Elemental Times
Element No. 11

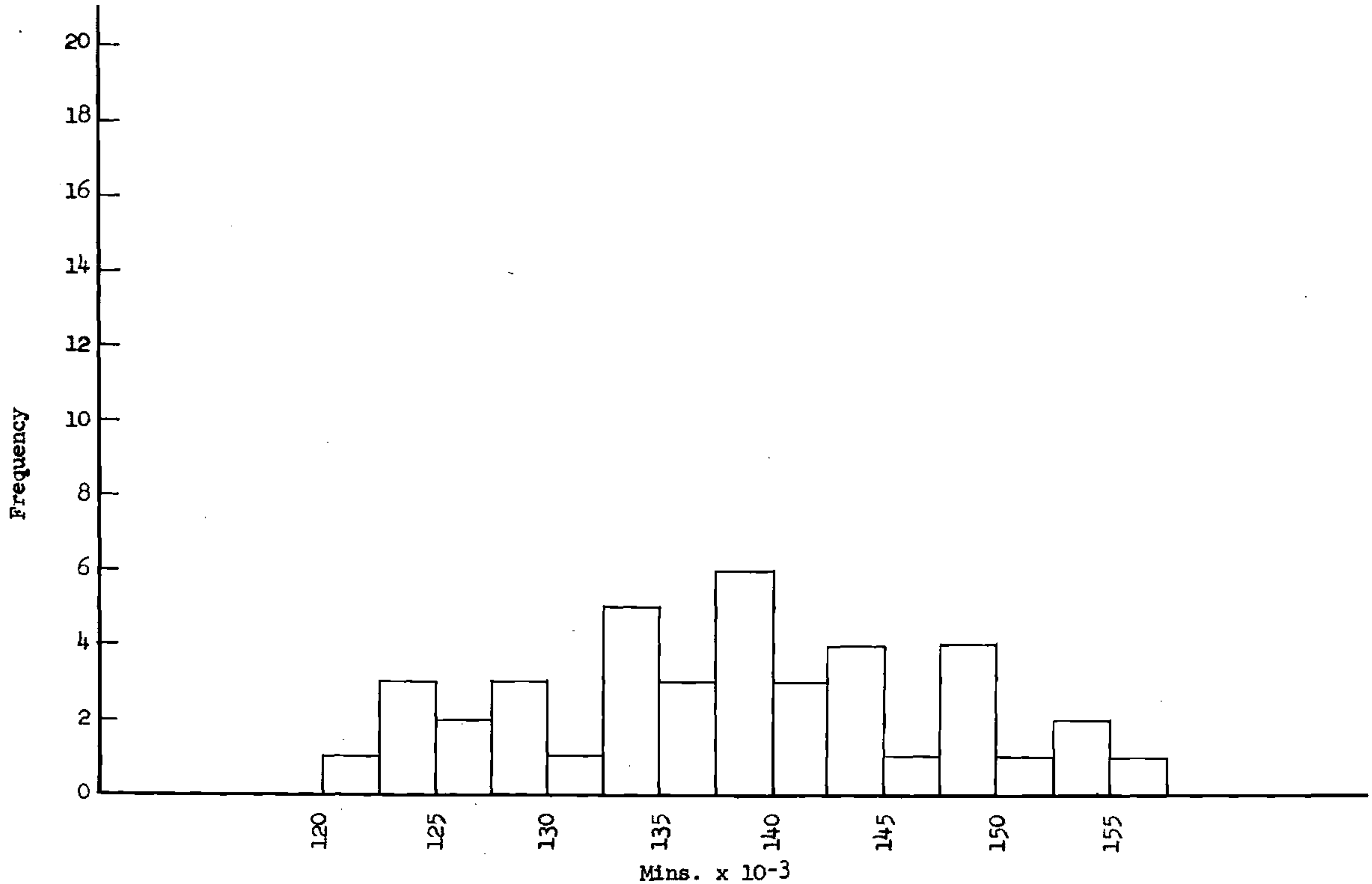

Figure 12. Frequency Distribution of Total Cycle Times
Sum of Controlling Elements

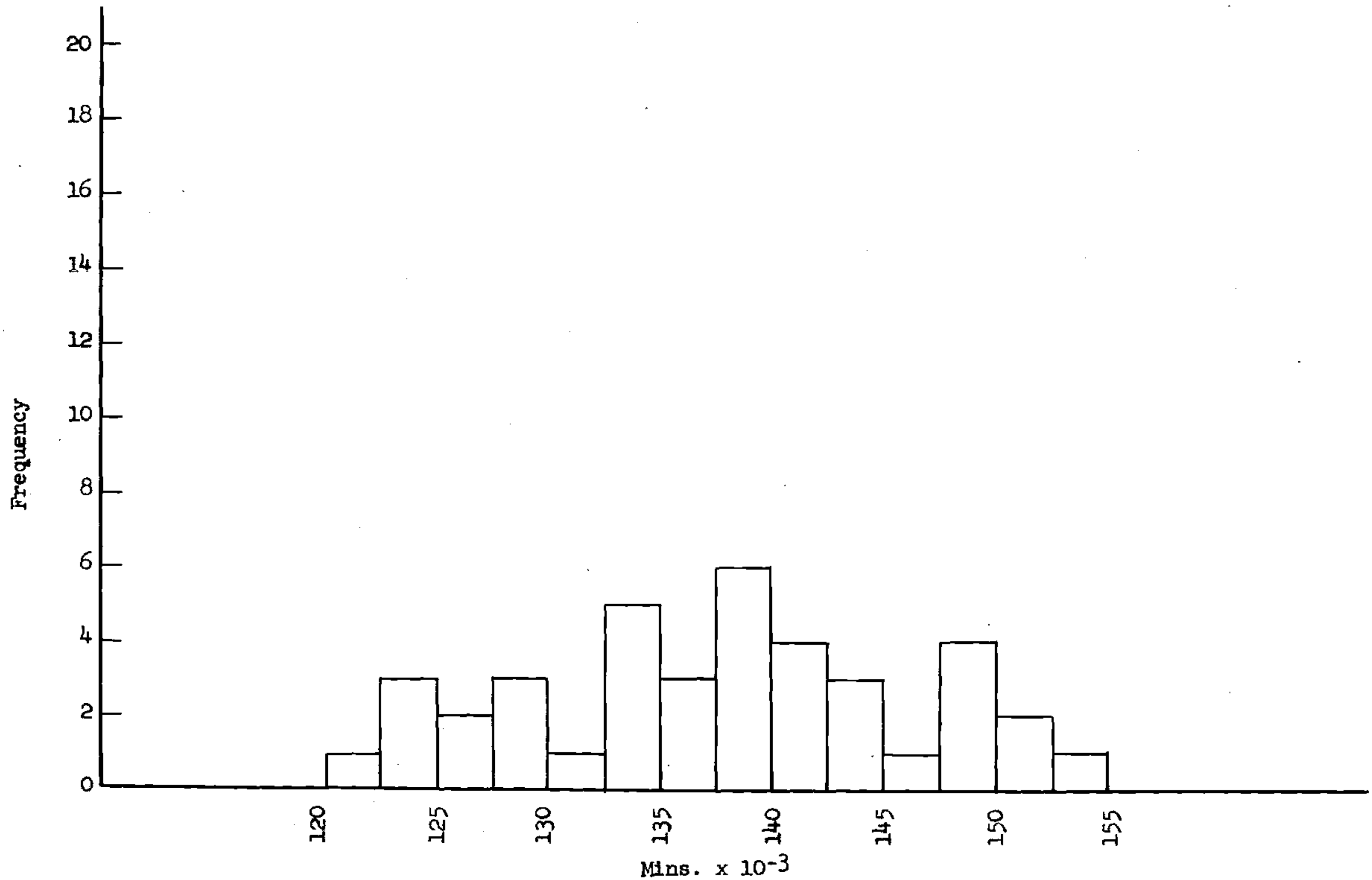

Figure 13. Frequency Distribution of Total Cycle Times
Sum of Elements of One Hand

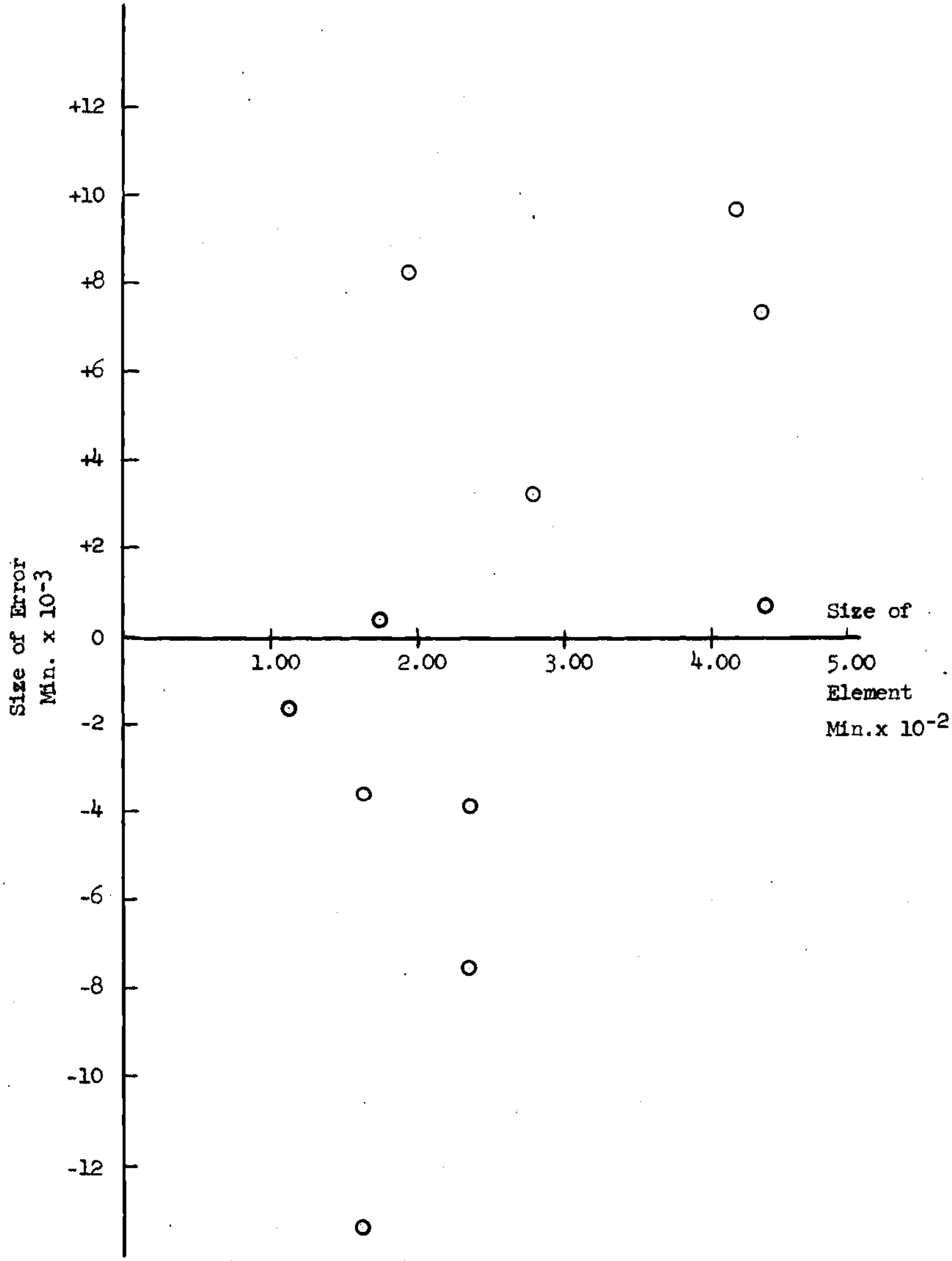

Figure 14. Size of Error - vs - Size of Element. BMT System

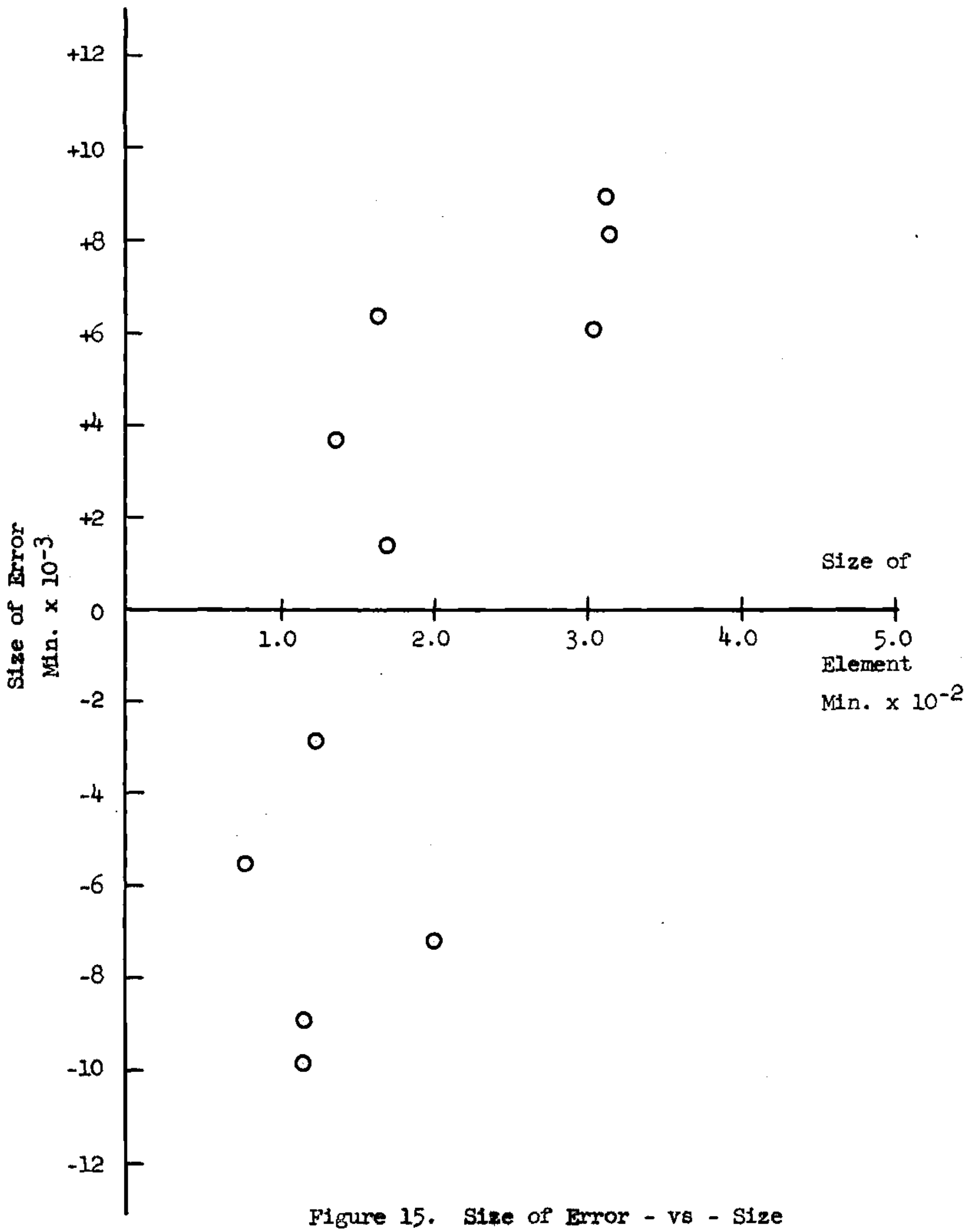

Figure 15. Size of Error - vs - Size of Element. MTM System

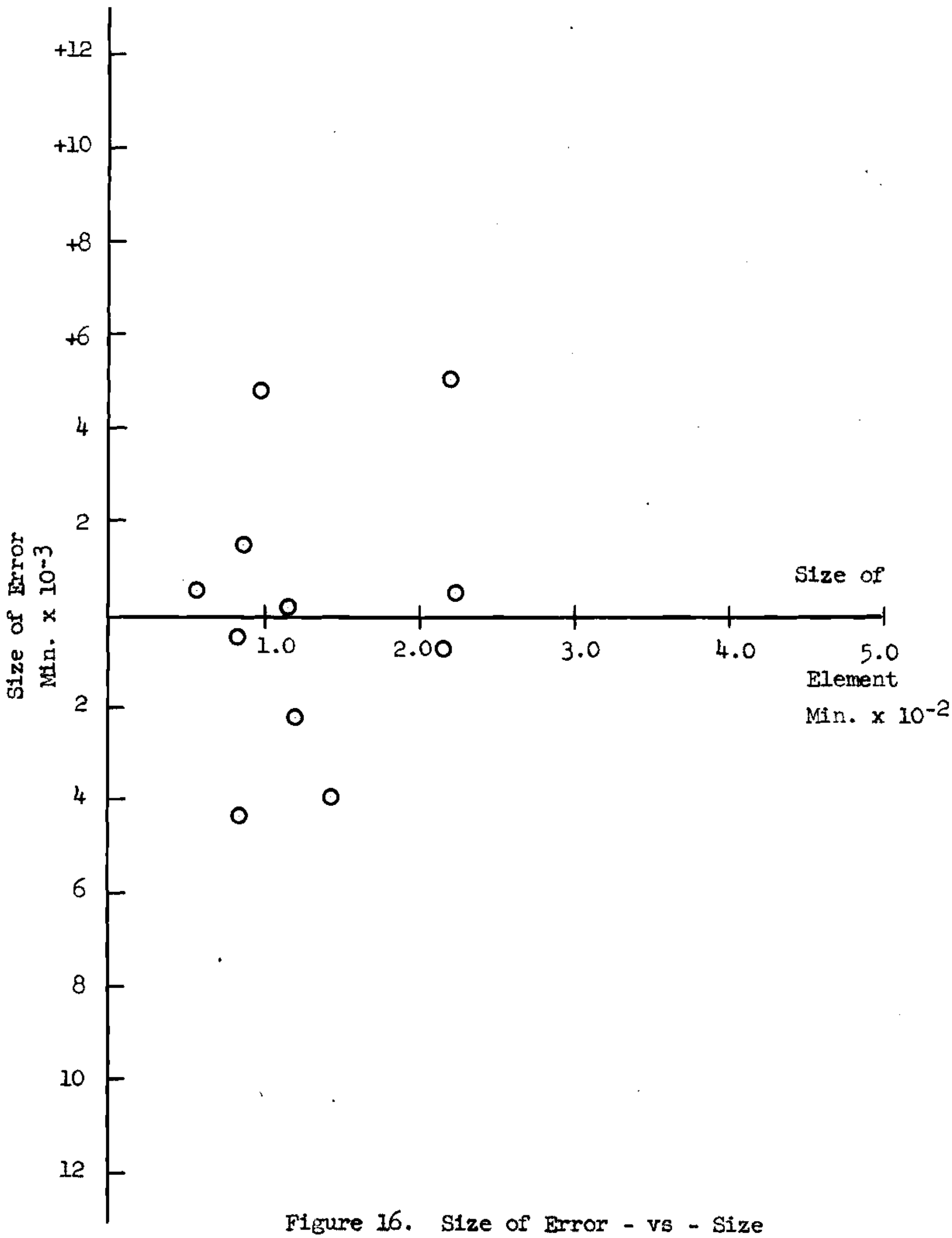

Figure 16. Size of Error - vs - Size of Element. Work Factor System

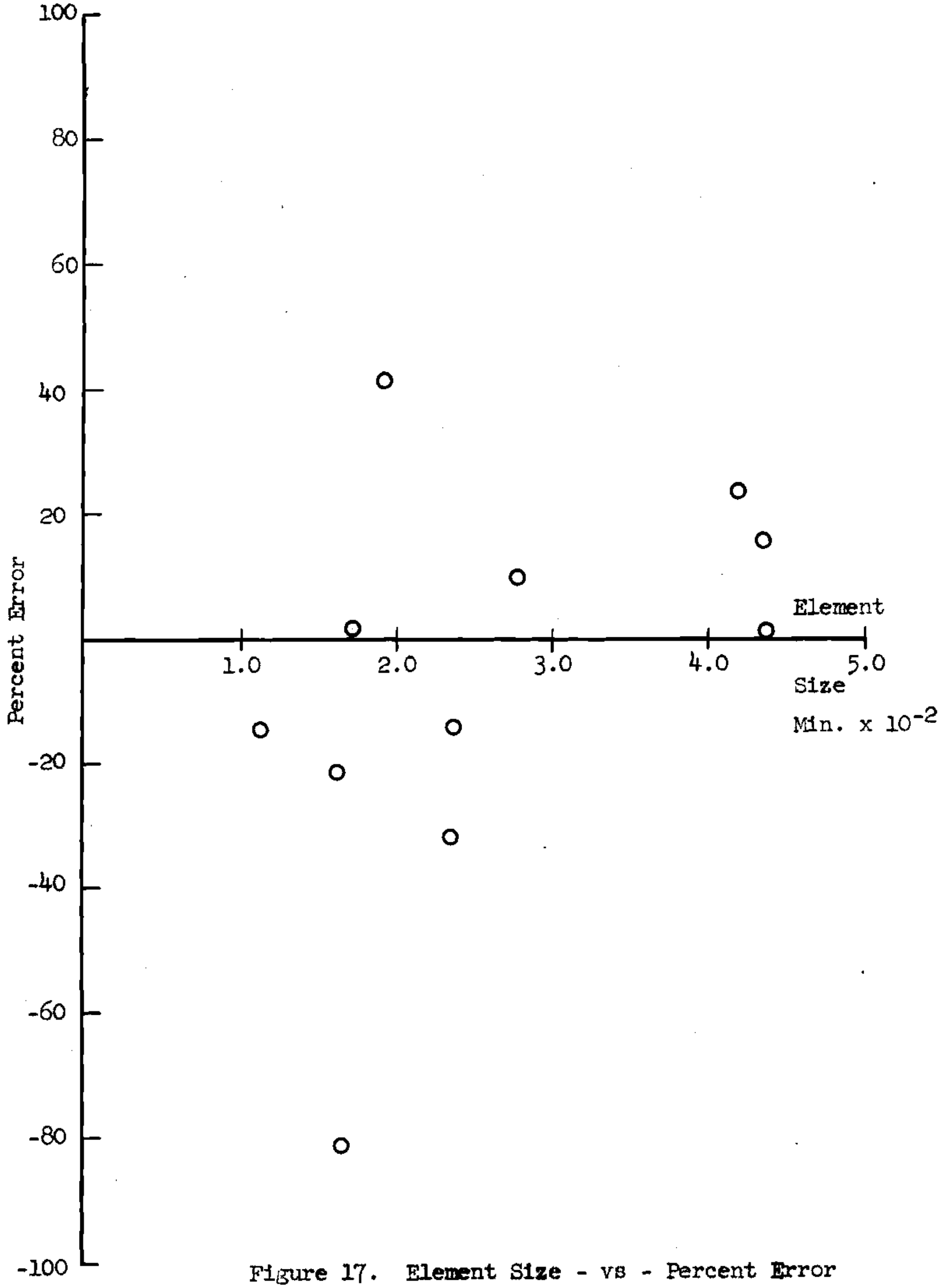

Figure 17. **Element Size - vs - Percent Error**
BMT System

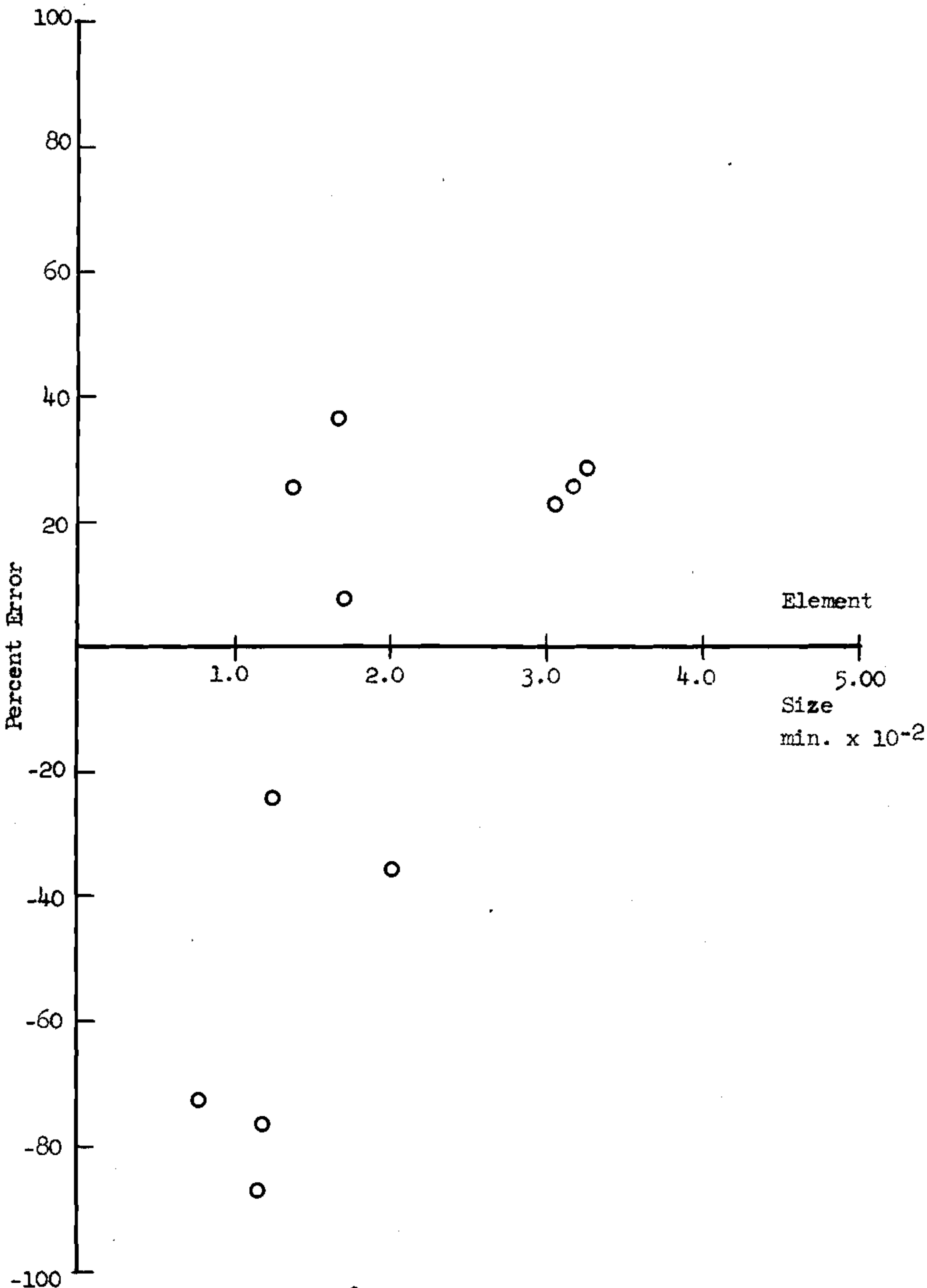

Figure 18. Element Size - vs - Percent Error
MTM System

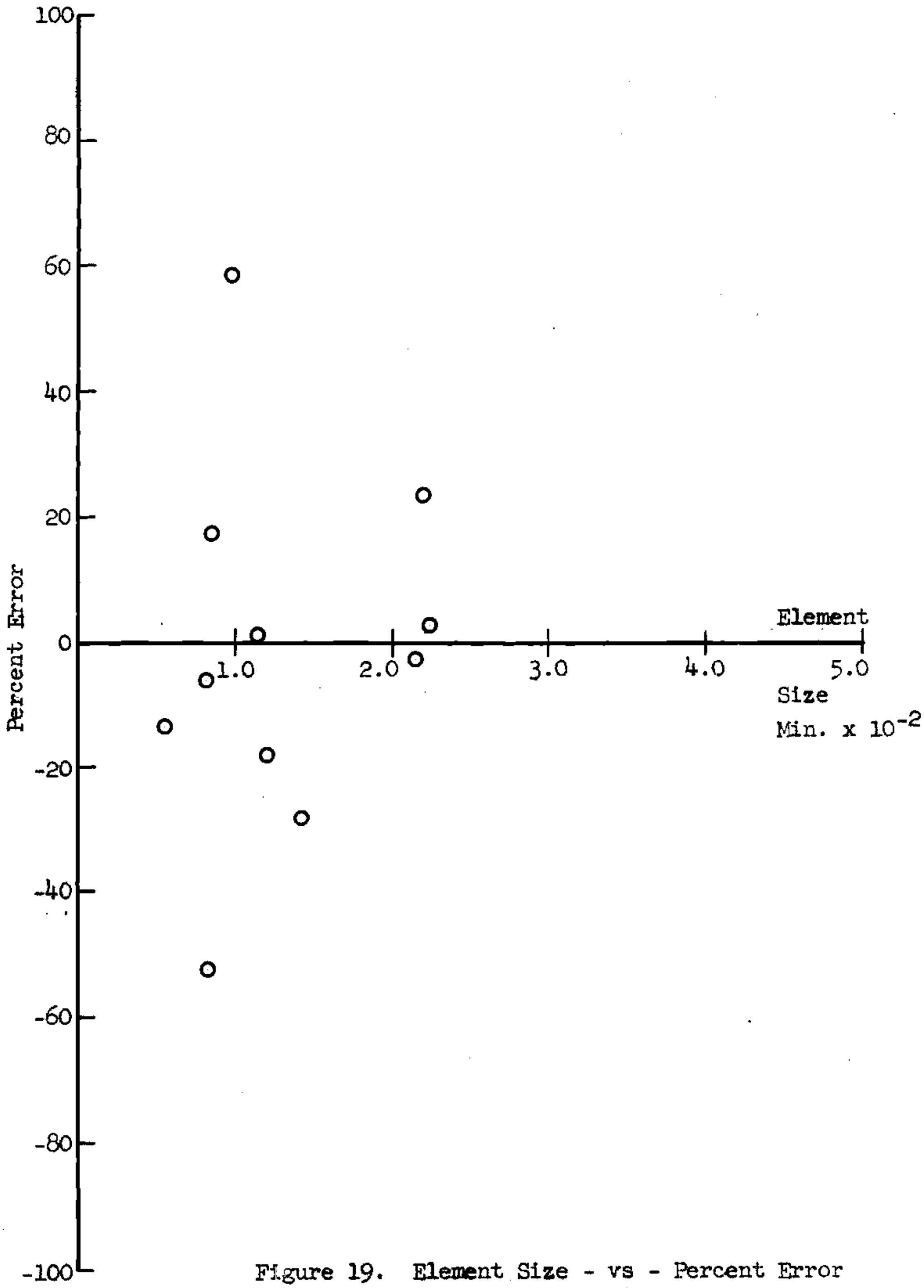

Figure 19. Element Size - vs - Percent Error
Work Factor System

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